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HITPRO TESTS AND ANALYSES

PRINCIPAL INVESTIGATOR AND COMPILER

STANLEY M. BIRLEY

SEPTEMBER 1976

FINAL REPORT

U.S. ARMY ARMAMENT COMMAND

RESEARCH DIRECTORATE

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HITPRO is an engineering model that digitally simulates the interactions of the major subsystems of direct fire surface mobile weapons in order to determine overall system accuracy. This report documents the technique used to validate the model with live firing tests.

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ACKNOWLEDGEMENT

1. In addition to the sources of information cited in the report the following are acknowledged:

Report Section	Source
2.2.3.2	Memo 5320-510, General Electric Ordnance Systems, "M60A1E2 Calibration"
2.3.2	Memo CDE 6231-54, Chrysler Defense Engineering "M60A1E2 Control and Stabilization System - Requirements for the Instrumentation on the Special Test Program for HITPRO"
2.3.3	Calibration Procedures, Chrysler Defense Engineering
2.	Report, General Electric Ordnance Systems, "MICV-65 Test Support for HITPRO II Validation Tests," dated July 1973, by A. R. Hazelton
3.1	Memo CDE 6231-57, Chrysler Defense Engineering, "The HITPRO Data Processing Procedure," dated 7 March 1972, by P. W. Hyde and C. R. Wells
3.4	Technical Note R-TN-75-026, Rock Island Arsenal, "Gun Stabilization Accuracy Evaluated Using Simple Film Reading Technique," dated August 1975, by C. A. Burnham
5.2	Technical Note R-TN-74-019, Rock Island Arsenal, "Comparative Evaluation of the Electro-Hydraulic and All-Electric Stabilization Systems Developed for the M60A2 Tank," dated August 1974, by Lorraine D. Wright
6.2	Letter, General Electric Ordnance Systems, 3 March 1971 Presentation, "G. E. Investigation of Fire Control Principles," dated 10 March 1971, by P. G. Cushman
6.3	Letter Progress Report, General Electric Ordnance Systems (GEOS), "M60A1E2 Demonstration Fire Control System," dated 30 June 1971, by P. G. Cushman and A. M. VanBlarcom

Report Section	Source
6.4	Letter Report, General Electric Ordnance Systems, "Non-Firing Test Results - M60A1E2 Demonstration Fire Control System," dated February 1972, by P. G. Cushman
A.3	Draft Report, "Electro-Hydraulic Control System Model," not dated, by Robert Kasten
C.1	Appendix C.1, "Digital Tapes," not dated, by Lanny D. Wells

2. A personal acknowledgement is made to John Mandzy, Robert Kasten, C. Allen Burnham, Harold Liberman, Paul G. Cushman, Walter Quick, A. M. BanBlarcom and Robert Conroy for their dedicated participation and support in these HITPRO tests and analyses.

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FOREWORD

During the period May 1969 through December 1974 the HITPRO methodology was developed and applied.[1] HITPRO, an acronym for hit probability, simulates an armored vehicle weapon system, engaging a moving target, while traversing a known terrain. In order to accurately predict the aiming point of the weapon system, all subsystems that substantially affect the aiming point are modeled. Validation is based on proving ground data collected on two testbed M60A1E2 tanks and on a testbed MICV-65. This work is attributable to Rock Island Arsenal, General Electric Ordnance Systems, and the cooperation and support of the Army Materiel Systems Analysis Activity, the Project Manager Offices - M60, MCV, VRF, and Chrysler Defense Engineering.

The Data Collection and Reduction Sections contain details of the tests, instrumentation, and data reduction procedures used to provide the experimental data for model verification. The HITPRO Validation Section provides the data analyses and comparisons used in accepting the HITPRO models of the M60A1E2 tanks and the MICV-65. The Stabilization Section documents data used to compare all electric and electro-hydraulic stabilization systems developed for the M60A1E2 tank testbeds. The Improved Fire Control Section contains: 1) an analysis of lead errors observed during APG firing tests; 2) the synthesis and analysis, using HITPRO, of gunner aid concepts to improve the lead solution; and 3) the results of non-firing gunner aid tests.

---

[1] (C) HITPRO, Volume I, II and III (U), AD519186, AD891400, and AD891401L, respectively; (C) HITPRO, Volumes I, II and III (U), AD529310, AD917763, and AD917794L, respectively; Study of Gunner Aids for Automatic Cannon Type Weapons, AD772000; and (C) Investigation of Methods to Quantify Control System Errors (U), AD521946.

1.0 INTRODUCTION

The HITPRO (i.e., HIT PRObability) program digitally simulates a vehicle direct fire weapon system engaging a fixed or moving target while traversing a known terrain. In HITPRO, the interactions among all subsystems affecting pointing accuracy are modeled; these include the suspension system, the fire control computer, the weapon stabilization system, the gunner and the motion of the targets. For an automatic cannon weapon system, recoil forces are also simulated. The inputs required by this model include a set of parameters that mathematically describe the vehicle, the weapon stabilization system, the target motion, projectile ballistics and dispersion, and a profile of the terrain. Extensive output is available to describe the performance of the vehicle and its subsystems, including linear and angular motions of the hull, turret and gun, fire control computer outputs, gunner commands, pointing error and information on internal states of the subsystems.

Initially, HITPRO was developed to represent a testbed M60A1E2 tank and to have provision for future extension to other direct fire weapon systems. A M60A1E2 tank was selected for the original modeling because a testbed M60A1E2 with General Electric all electric gun stabilization was available for critical data collection and because the GE stabilization had surpassed all systems tested by APG to that date.[2]

The nonfiring tests performed at APG in the Fall of 1970 established that HITPRO accurately represented the subsystems of the testbed M60A1E2 tank, serial number 09A02867. The firing tests confirmed the HITPRO predictions that the lead solutions were too small and were sensitive to dynamic cant. Consequently, confidence in the model was established and this new analytical tool was employed to screen techniques and concepts having potential to improve the lead solutions. The most promising of these were implemented into the testbed. Again, HITPRO provided outputs similar to that of the actual hardware testbed. In 1971 and 1972 engineering tests were performed at APG and the Yakima Firing Center.

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[2] (C) Final Report on Engineer Design Test of Optimum Ratio Electrical Stabilization System for 105MM Gun, Tank, M60 (U).

This critical data was used to verify the HITPRO models of the M60A1E2 tank with electro-hydraulic gun drives and of the MICV-65 with all electric gun stabilization.

2.0 DATA COLLECTIONS

2.1 AMXRD-AWF Position Paper

Mr. Conroy/myl/234-
3350-3675

AMXRD-AWF

SUBJECT: Fire-on-the-Move Hit Probability Mathematical Model

Commanding General
U. S. Army Materiel Command
ATTN: AMCRD (COL Richter)
Washington, D. C. 20315

1. On 25 June 1970, representatives of the U. S. Army Weapons Command (USAWECOM) and the General Electric Company (GE) visited the Army Materiel Systems Analysis Agency (AMSAA) to discuss a "fire-on-the-move hit probability mathematical model." Following that meeting AMSAA received a copy of the request to AMC (AMCRD) for funding of firing tests of the M60A1E2 to validate the model thereby "increasing USAWECOM's capability for making future surface mobile weapon stabilization decisions and recommendations." The final paragraph of the letter transmitting AMSAA's information copy of the request for funds concluded: "any support you (AMSAA) may be able to provide to AMCRD-G will assist in assuring that adequate testing will be carried out."

2. AMSAA's position concerning the "fire-on-the-move hit probability mathematical model" and the validation testing is given below.

3. AMSAA is in agreement that (1) adequate data and/or predictive methodology does not exist for either guiding the development of stabilization systems or evaluating the contribution which stabilization can make to combat effectiveness, and (2) testing to validate a proposed analytical model is required both to insure that the model does predict responses which are compatible with test results and to provide the necessary credibility to permit the predictions to influence pertinent decisions.

4. The advantages of using the M60A1E2 with the GE stabilization system are as follows:

a. The model, if testing confirms its validity, can be moderately easily adapted to provide reasonable estimates of stabilization performance in the M551, M60A1, and MBT-70;

b. the equipment is available for testing; and

c. the necessary model input is currently available only for the M60A1E2 and GE stabilization system.

AMSAA would be pleased, for the above reasons, to see the results of the program USAWECOM discussed with AMSAA on 25 June 1970. In fact, AMSAA plans limited participation in the planning, testing, and analysis of test results to insure that the results are compatibly examined and used in the evaluation of fire-on-the-move capabilities of tanks.

5. The following additional comments are offered to clarify what AMSAA expects to be able to do as a result of the testing if validation is achieved as well as AMSAA's planned participation and understanding of the outline of the test.

a. AMSAA hit probability estimates have generally been for stationary vehicles firing at stationary targets under "quasi--combat" conditions. The output of the "fire-on-the move hit probability mathematical model" does not provide similar hit probabilities for moving vehicles for two reasons:

(1) First, some of the "quasi-combat" stationary vs stationary error sources will also be involved in firing on the move, others will be somewhat modified, and some will be replaced by the output of the model. The best method for processing the math model output will be to consider it as providing information on a few of the error sources which must be considered to obtain "quasi-combat" hit probabilities.

(2) Secondly, frequency (of occurrence) distributions have been developed for such error sources as cant, crosswind, jump, etc., for the stationary vs stationary situation. The utilization of these frequency distributions permits the calculation of average "quasi-combat" hit probabilities which generally are exhibited only as a function of range. There presently does not exist frequency distribution information to adequately describe vehicle speed, terrain roughness, target bearing, target speed, target direction, etc. These and other factors will have to be addressed and their contributions synthesized with the output of the USAWECOM simulation model.

b. The AMSAA review of the math model was performed by personnel whose expertise is not in electronics and/or kinematics. AMSAA considers that the responsibility for technical adequacy of the assumptions and equations to relate terrain description to vehicle motion does and should belong to USAWECOM and GE. AMSAA does concur that the predictions resulting from the model, if representative, are the key elements for relating vehicle dynamics of tanks to fire-on-the-move delivery accuracy.

c. It has been AMSAA's experience that anomalies inevitably are encountered in tests of this magnitude. The ten replications described in the USAWECOM plan are therefore thought to be inadequate. If cost restraints were not present 30 replications would be desirable, but considering cost AMSAA requests that provisions for approximately 20 replications be made. If necessary this could be accomplished by not firing ammunition in the additional replications and/or reducing the variety of test conditions. In any case, the test should not be so rigid that analysis of emerging results could not influence the test in restricting the presently planned variety and/or changing the number of replications within the previously established funding constraints.

d. The results of the test required for analysis are:

(1) ammunition impact points,

(2) gunner's aiming error at end prior to the firing time,

(3) position of gun cradle axis at and prior to firing time,

(4) sufficient measurement of accelerations, displacements, and/or forces to permit resolution of differences in road wheel motion and vehicle-stabilization system responses to identify causes of major discrepancies between measured test results and the model predictions,

(5) Other measurements, such as muzzle direction, would add significantly to the information obtained but are subject to cost restraints and/or availability of adequate instrumentation.

e. AMSAA believes that even if the math model gives a perfect representation of the vehicle and gunner responses, it is impossible to obtain a perfect match between test conditions and model input. However, it is expected that the differences can be sufficiently small that the model can provide a representation of the basic character of the motions, and this is what is necessary to improve our capability to predict fire-on-the-move delivery accuracy.

f. If the proposed test is completely successful, AMSAA will have a significant tool to assist the understanding of the nature of the contribution of stabilization to fire-on-the-move delivery accuracy improvement. It is expected that the thus validated methodology could provide insight into performance on other terrains as well as for other vehicle/stabilization systems such as the M60A1 with add-on stabilization and the MBT-70. However, this would provide a basic element requiring further modification and validation for such things as the FRG's tri-axis stabilization and the MICV or ARSV firing a rapid fire weapon.

6. In summary, it is felt that the effort proposed by USAWECOM would be a major step toward overcoming the evident weakness in AMC's capability to evaluate stabilization both from the design viewpoint (USAWECOM's major concern) and from the effectiveness viewpoint (AMSAA's major concern). Therefore, it is recommended that the program be pursued if at all possible. AMSAA has initiated action to transfer $60,000 to USAWECOM in support of the proposed program.

FOR THE DIRECTOR:

MORGAN G. SMITH
Chief, Ground Warfare Division

Copy furnished:
CG, USAWECOM
ATTN: AMSWE-REV (Mr. Garver)

2.2 M60A1E2 Tank/All Electric Gun Drives

2.2.1 Background

In 1965, the United States Army Weapons Command encouraged General Electric to develop an all-electric tank main armament stabilization system. This system was installed in an M60 and based on subsequent Aberdeen Proving Ground (APG) test results, the system design was developed as a back-up and installed in two M60A1E2 tanks for the PM-M60. In May 1970, it was determined that a back-up system was not required for the M60A1E2 tank. Thereupon, the test responsibility was assigned to the Tank Systems Laboratory, Research and Engineering Directorate, HQ, USAWECOM.

The purpose of this test was to evaluate the stabilization of the main weapon while firing on the move, collect test data suitable for validation of the HITPRO computer mathematical model and to ascertain gunner and loader human factors in the GE stabilized M60A1E2 tank. One of the two prototypes located at APG was used in the test. Preparation of the testbed M60A1E2 tank, serial number 09A02867, began 14 September 1970 and testing was conducted from 28 October to 11 December 1970 at Aberdeen Proving Ground.

General Electric was responsible for provision, installation, calibration, maintenance, and operation of most of the instrumentation; in addition, they provided system maintenance and data reduction.

Chrysler provided maintenance of the fire control other than the GE stabilization.

United States Army Weapons Command was responsible for preparing the test plan, conducting the test, and compiling the final report; USAWECOM was assisted in the preparation and conduction of the test by AMSAA, MTD, and HEL.

2.2.1.1 Description of Material

a. The stabilization system controls the cupola and the main gun; however, in this test only the main gun was of interest.

The turret is capable of 360° of traverse at rates of up to 45°/second; the main gun will elevate from -10 degrees (depending on orientation) to 20 degrees at rates up to 40 degrees/second.

The optimum ratio stabilized power drive is an all-electric solid state power drive. A pair of gun mounted integrating rate gyros detect space velocity in the traverse and elevation planes. The D.C. gyro voltage is proportional to the space velocity; this voltage is amplified and converted into the proper form for controlling the magnitude and direction of current through the D.C. motors.

The stabilization system consists of the following assemblies: traverse-elevation power drives, traverse-elevation manual drives, hand controls, junction box, power controller, low level electronics, D.C. converter, and the power electronics. (See Figure 1.)

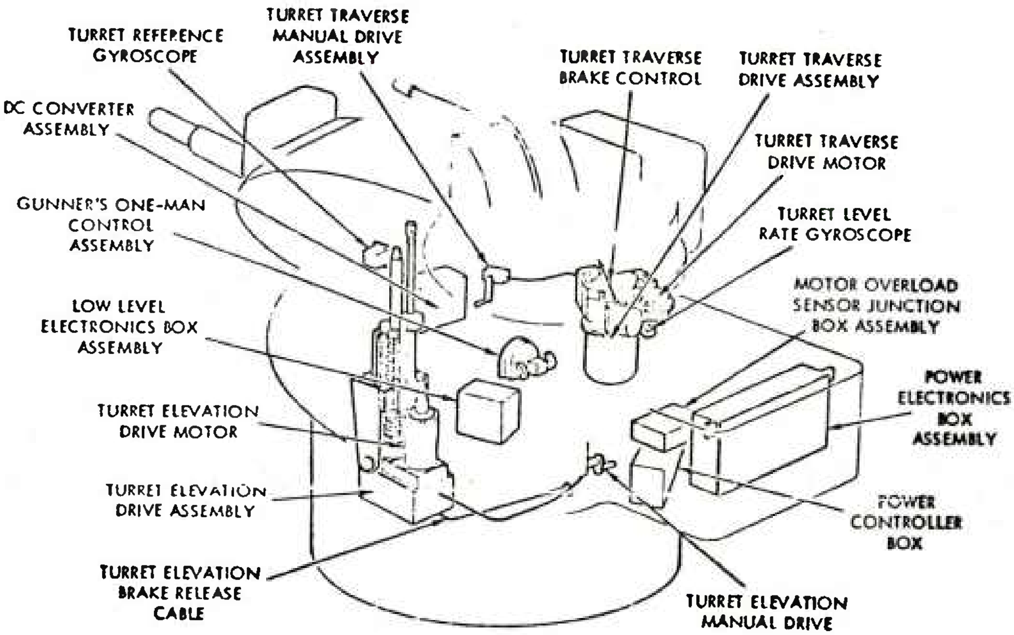


Figure 1 M60A1E2 Tank Stabilization Drives

b. The turret can be traversed or elevated manually or by power. The drive system consists of a clutch, gearing, drive motor, and a brake; in addition, the elevation drive contains a ball screw.

The hand controls consist of two handles, two palm switches, a firing key, and lead input-lead cancel buttons. The control assembly can be operated by depressing one or both palm switches: depressing both palm switches gives maximum slew rate, and depressing either one of the palm switches yields a slew rate one-fourth that of the maximum.

The junction box senses motor overload and it contains four thermal action relays. The power controller isolates vehicle power from the power electronics, provides power line filtering, and it contains a time delay to prevent operation of the stabilization system until the gyros are up to speed. The low level electronics supplies an A.C. reference voltage to the system and to the servo-electronics for the power drives. The D.C. converter takes the unregulated 16-32 vdc from the tank, and converts it to the required regulated levels. The power electronics amplifies the signals from the low level electronics for the power drive motors.

Unlike hydraulic systems, this design has such a low noise level that the turret rotation is not normally sound detectable at the turret swing radius. The system has no high voltages and it precludes the need for high pressure hydraulics and flammables.

2.2.1.2 Test Objectives

It was desired to evaluate the stabilization of the main weapon while firing on the move, collect test data suitable for validating the HITPRO computer mathematical model, and to ascertain gunner and loader human factors.

2.2.1.3 Scope

The testing was comprised of firing on the move at stationary and moving targets; as tank related problems presented themselves, diagnostic data was generated by firing at a moving target with a stationary tank in an attempt to further isolate the problems. The test courses utilized were bump, gravel, zig-zag, and cross country. Due to time and priority limitations only 190 out of the approximately 490 rounds requested were actually fired.

2.2.2 Details of test

2.2.2.1 Non-Firing Phase

a. Objective:

The objective of the non-firing phase was:

1) To determine the need of the split beam camera being used as an indicator of the gunner's reticle position.

2) To ascertain relative motion between the gun tube and the mantlet.

3) To check out instrumentation and procedures for the ensuing firing runs.

4) To determine the gunner's capability to accurately and consistently lay on the center of the turret ring of a tank-like target silhouette.

b. Method:

The centerline for the mantlet and gun tube cameras, V-block telescope, and muzzle telescope were taped on a 500-meter grid board as they were related to one another on the tank. The collimated V-block telescope was aimed at its mark and then each camera was aimed on its respective mark; this established parallel axis for these instruments and some film was then exposed for record. (See Figure 2.)

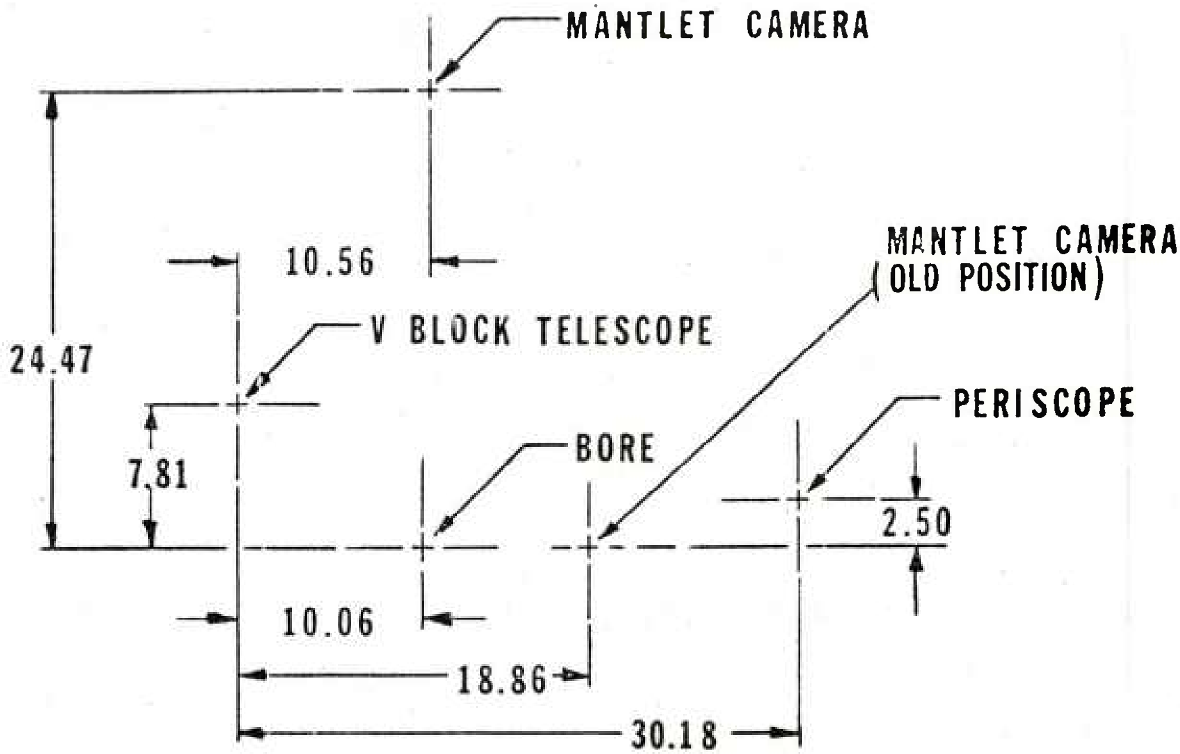


Figure 2 Instrumentation Alignment
(All Dimensions in Inches)

Runs were conducted over the bump, gravel, and zig-zag courses. Procedures for live firing runs were used except that all loading operations were simulated.

Next, each gunner aimed at the center of the turret ring on the target silhouette from ranges of 1500 meters and 500 meters; then a few frames of film were exposed. After each aiming, the turret was slewed off target, the gun was elevated, and the brow pad was loosened. Each of the two gunners aimed at the target five times from right to left to right for each range.

Excessive lateral motion was detected in the mantlet camera mount position on the side of the mantlet; therefore, a new mount was fabricated and installed on the top of the mantlet. (See Figures 3 and 4.)

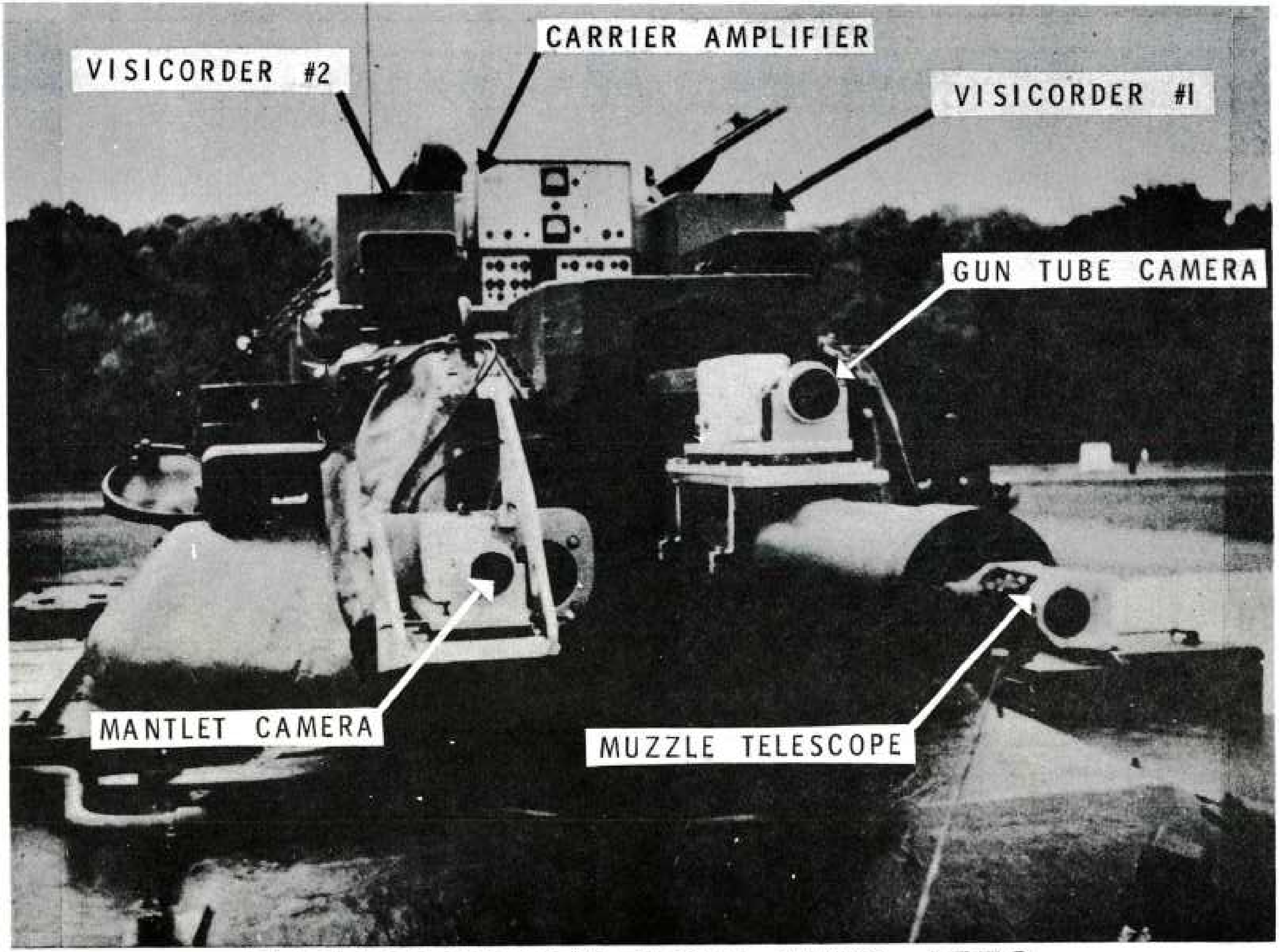
2.2.2.2 Zeroing Procedure

a. Objective:

To establish an accurate zero setting for the live firing, while on the move test.

b. Method:

A 20x20 foot target containing a bull was positioned 1200M from the tank muzzle. The tank was positioned on a level concrete pad with the gun aligned to the hull. Cross hairs were taped onto the muzzle and a chamber telescope was inserted and aligned to the cross hairs in the gun muzzle. All computer knobs were initially set to zero, the computer was turned on in the boresight mode, a 1200M range was dialed in, and the cant unit and stabilization were turned off. The gun tube was positioned on the target by sighting through the chamber telescope-cross hair combination and manually cranking the gun. The gunner's reticle was made to coincide with the gun tube by adjusting the boresight knobs. Jump information for the ammunition being used was introduced into the computer with the jump knobs. The computer was then placed in the normal mode and 10 zeroing rounds were fired with the emergency fire switch. After firing each round the gunner re-positioned the gun on the target. The center of impact (CI) for the resulting group was determined and marked on the target; the gunner moved the gun to the center of impact by using the jump knobs. This is best achieved by placing the reticle on the CI with the jump knobs instead of



INSTRUMENTATION M60 A1E2

Figure 3 Instrumentation M60A1E2

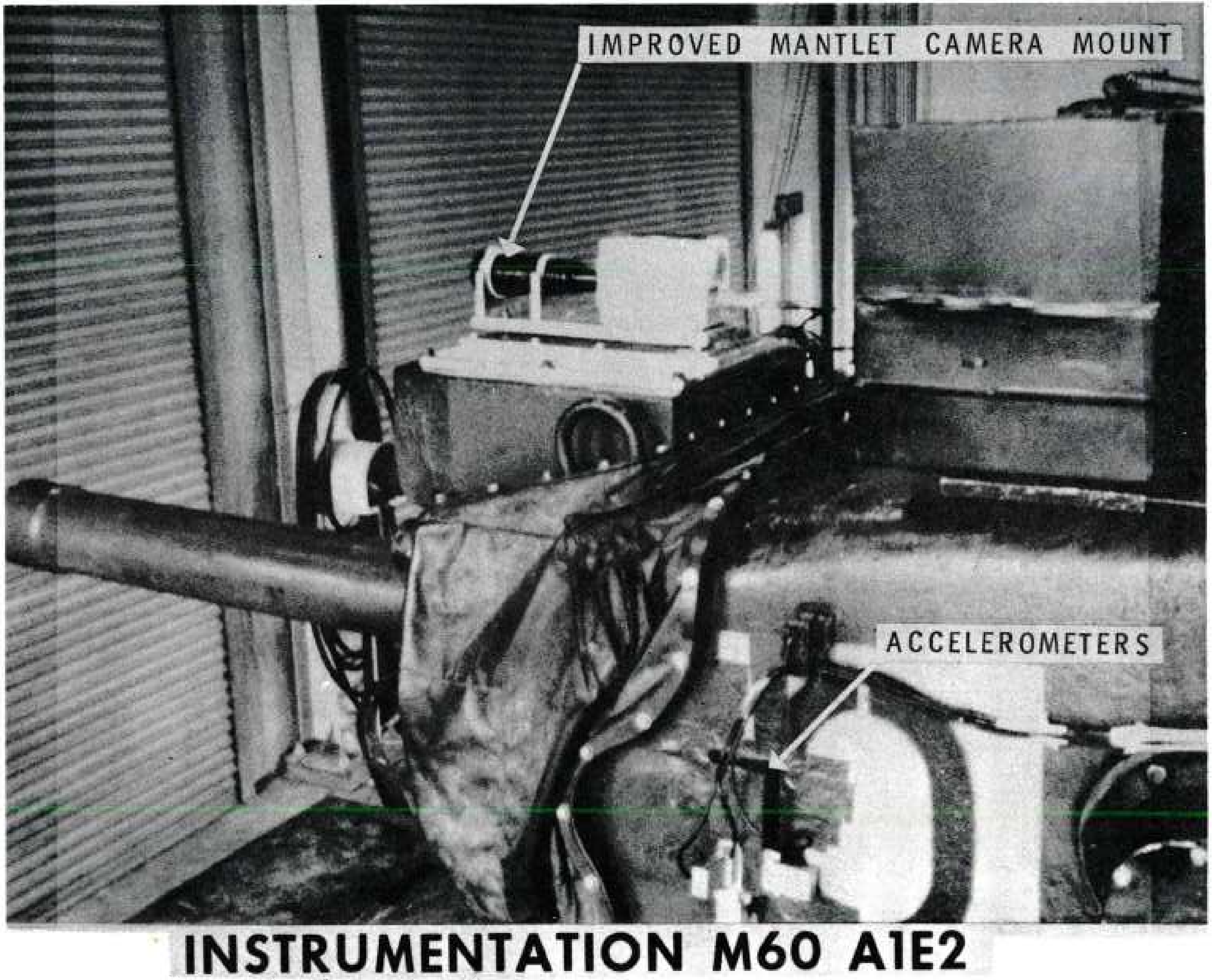


Figure 4 Instrumentation M60A1E2

inserting a corrective number of clicks on the jump knobs determined from CI coordinates on the target.

The colored knobs on the computer were labeled as elevation and deflection jump knobs, but sometimes during the test they were called zeroing knobs.

During the zeroing both the mantlet and the split beam cameras were run; in addition, meteorologic data was gathered.

2.2.2.3 Firing Phase - Bump, Gravel, and Zig-Zag Courses

a. Objective:

The objectives were:

1) To ascertain how well the stabilization system kept the gun on target.

2) To obtain the degree of accuracy that the computer program predicted hull motion.

3) To ascertain accuracy of the fire control computation.

b. Method:

Ammunition of the same lot was used throughout the test, XM411E4. The crew consisted of a commander, driver, loader, and a gunner.

Runs would start with a round in the chamber and the turret aligned with the hull. Two additional rounds were stored in racks to the immediate right of the loader and one dummy round on the loader's left.

A maximum of three rounds per run were fired; prior to loading a live round, the chamber was visually inspected with a mirror mounted near the breech. The dummy round was immediately loaded upon firing the last round to obtain human engineering data.

The starting range for the course was 1500 meters. (See Figures 5 and 6.) Range markers were located at even 50 meter increments, but placed 25 meters farther from the target than the indicated range.

When the gunner would normally range with the laser range finder, he'd announce range; at this signal, the commander would dial in the range displayed from the nearest range pole; then the commander would announce, "range-in", (See Page   for commands used). The driver ejected a "bean bag" through his escape hatch after firing each round to mark the

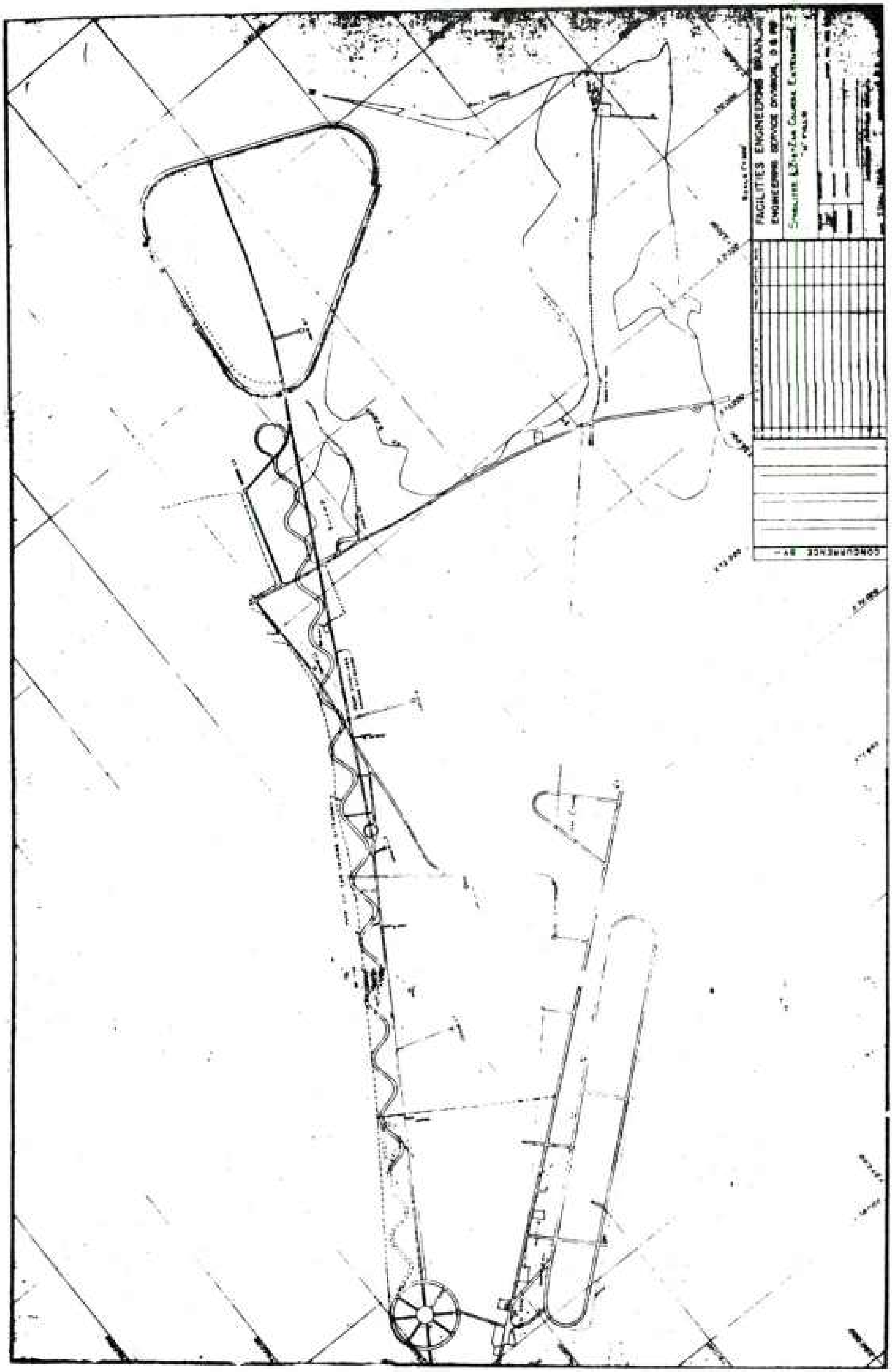


Figure 5 Stabilizer and Zig-Zag Course Extensions

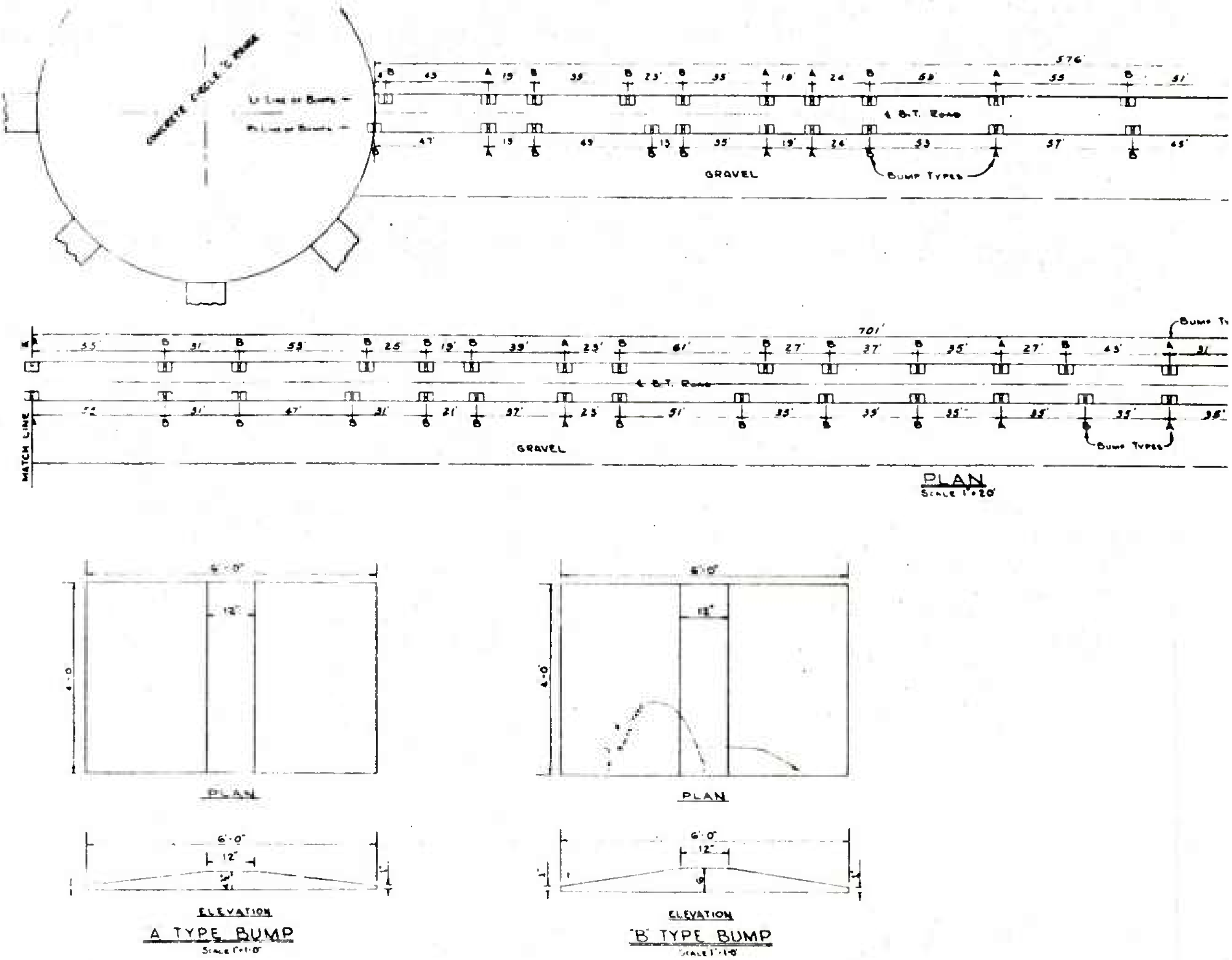


Figure 6 Details of Bumps

firing position. The commander, after the firing of each round, announced the range to the nearest 5 meters displayed on his manual range input.

During moving target runs, the target entered its straight section of track at the specified speed about the same time the tank reached the 1500 meter course marker. This straight section was marked, enabling the commander to give his fire command when the target entered the straight section.

Prior to firing the third round, if the target went beyond the straight section, the firing portion of the run was terminated. Simulated firing of the dummy round was still enacted as if the target was still moving at a constant crossing rate.

Two types of targets were used depending upon wind conditions. One type of target consisted of a black M551 silhouette painted on a white 20x20 foot canvas background with fiduciary marks in the upper corners to aid in film reading (See Figure 7); the other target consisted of an 8 inch white cross painted on a 7-1/2 x 7-1/2 foot black background centered on a large chicken wire holder (See Figure 8). The latter target was used in windy conditions.

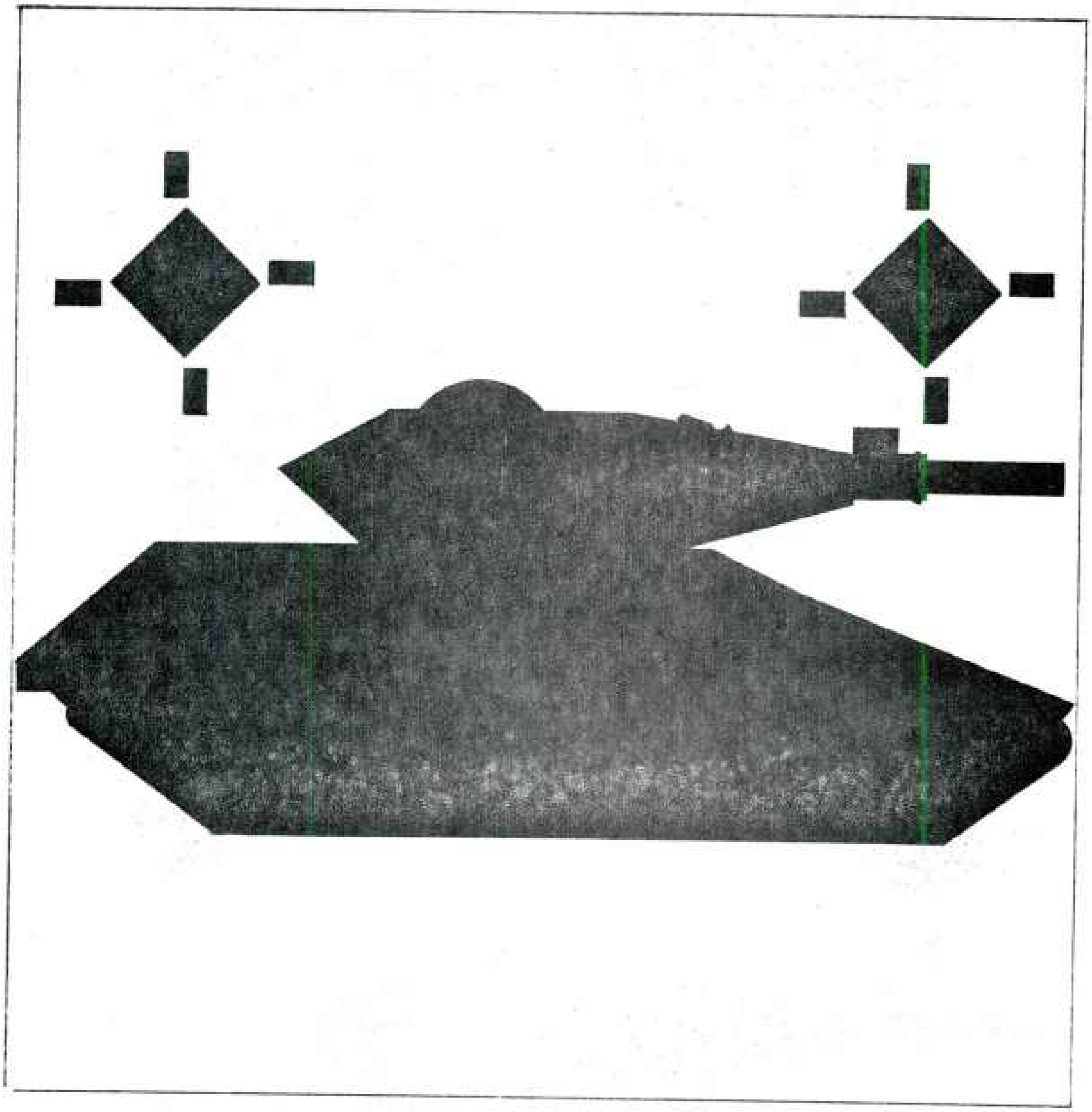


Figure 7 M551 Silhouette Target

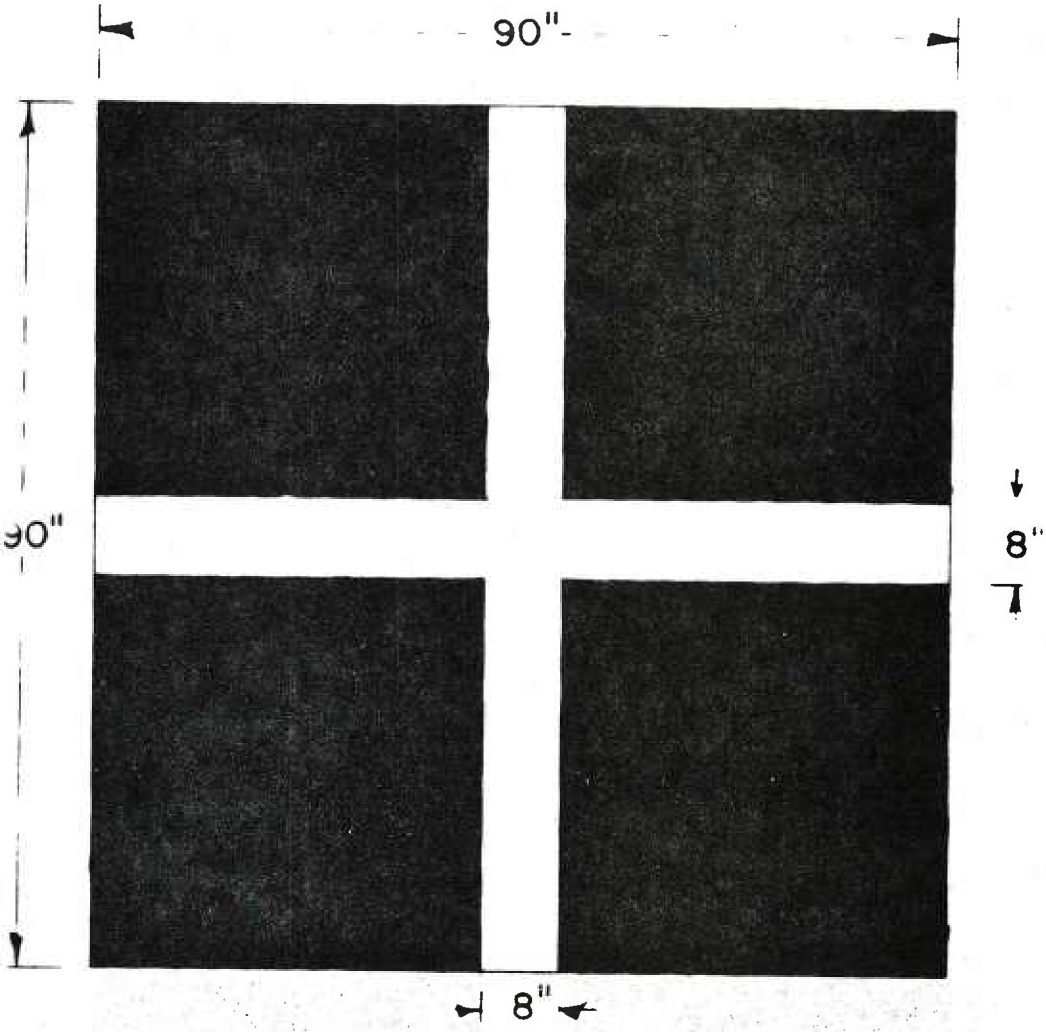


Figure 8 Cross Target

Up to three gunners were used in this test.

At the beginning and end of each day, readings were taken on a grid board located at a fixed distance from the tank. Readings for the following instruments were taken: V-block telescope, gunner's periscope, and the muzzle telescope. The V-block telescope after being collimated and aimed at a fixed point on the grid board served as a reference for repositioning the other instruments.

Next the V-block telescope was aimed at another point on the grid board where one could boresight the mantlet camera.

2.2.2.4 Firing Phase - Cross Country Course

a. Objective:

To facilitate possible future expansion of HITPRO to use as a quasi-combat prediction model.

b. Method:

The same as for other courses.

2.2.2.5 Firing Phase - Stationary Firings

a. Objective:

The objective was to investigate suspected computer problems.

b. Method:

The same as other courses, with the following exceptions:

1) Ranges for both stationary and moving targets were a constant 1500 meters. The number of rounds per run varied from two to five with no dummies used.

2) One gunner was used for the stationary target and another gunner was used for the 15 mph moving target.

2.2.3 Instrumentation

2.2.3.1 Recording Equipment

The initial phase of testing was conducted with instrumentation consisting of: two Honeywell 904 Visicorders, a carrier amplifier, an HEL event recorder, a mantlet camera, a gun tube camera, and a split beam camera. Electrical power for the instrumentation was supplied by a 3 KW generator mounted on the turret bustle.

The gun tube camera was used to ascertain relative movement between the mantlet and the gun tube during non firing tests over the bump course. On November 3, 1970 the gun tube camera was removed because no appreciable relative movement could be detected.

The mounting of most of this test equipment can be seen in Figures 3 and 4. The split beam camera was mounted inside the tank on the gunner's periscope, and the HEL events recorder was externally mounted on the left side of the turret bustle. (Channels are shown in Figures 9, 10, 11, and 12.)

Each of the visicorders was protected by a Lexan plastic cover because the instrumentation was susceptible to moisture and gun blast. Containers were used to collect the oscillograph paper and to protect the data from sunlight and gun blast.

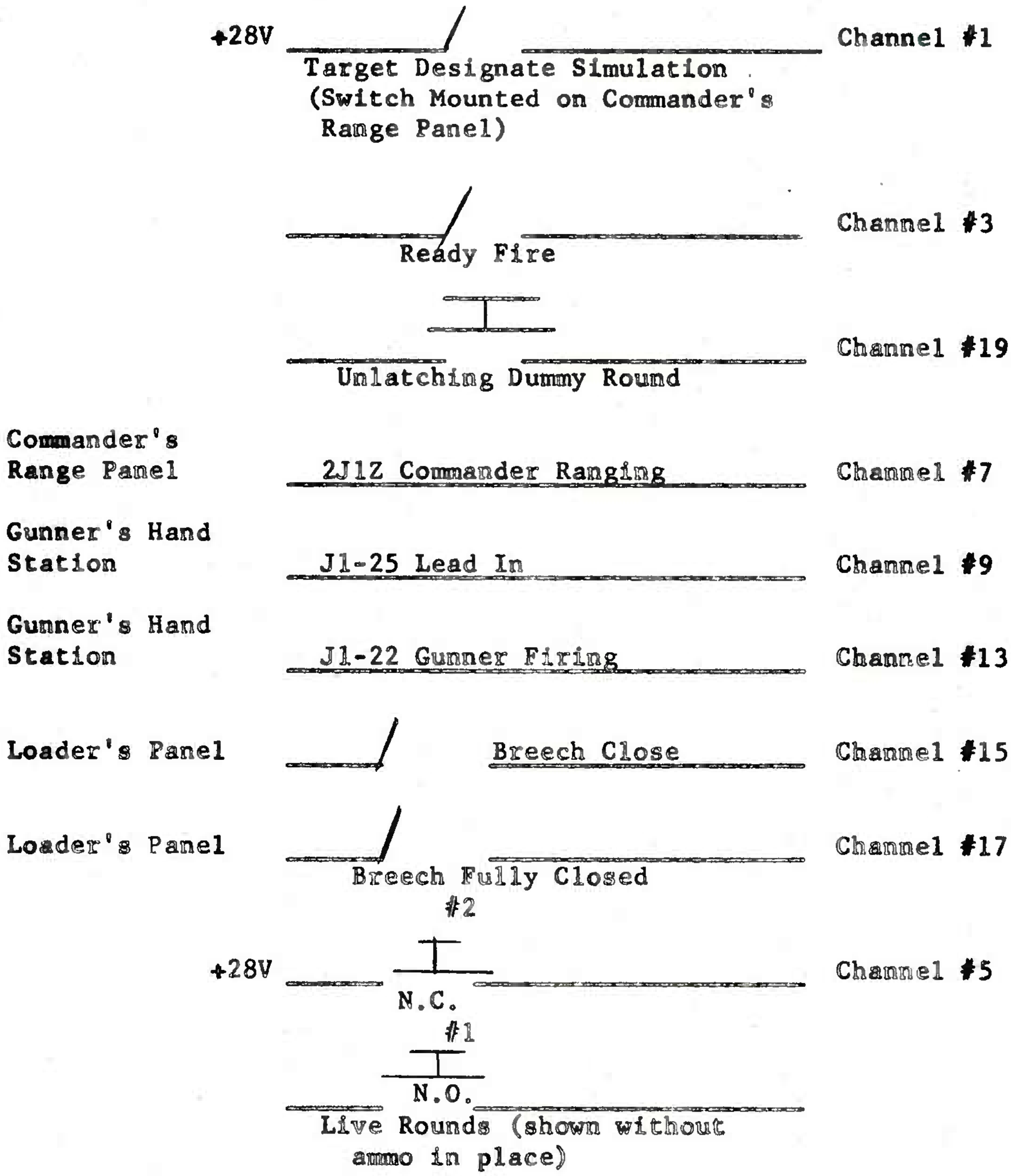
On December 1, 1970, twelve channels of duplicate instrumentation in the form of telemetering was added to the existing equipment for purposes of improved data reduction and scrutinization.

The test equipment wiring scheme is shown in Figures 13 and 14. This traces the instrumentation from the pick-off point - through any intermediate amplification - and on to the Visicorder from left to right. Therefore, information from the elevation rate integrating gyro is obtained from pins J3-A, B and C located in the low level electronics box - transmitted to the 10 amplifier box and then on to pins J 6 A and B of Visicorder number one.

The 10 ampere amplifier box referred to in the diagram is physically located behind the loader and the 2 ampere amplifier box is located on the left hand side of the gun tunnel. The carrier amplifier provided impedance matching for the accelerometers.

Additional detailed information concerning the instrumentation may be found in the memorandum: Hit Probability Study - Technical Support - Firing on the Move by J. Wright and P. Baldassaro (January 18, 1971) of General Electric Ordnance Systems.

HEL EVENTS RECORDER SCHEMATIC



Note: All switches must be on before start of runs.
2 switches mounted to left of ampl. box must be on at all times.
Switch on gunner's handstation is remote control for recorders and cameras.
Gunner must not override computer on Channel #7.

Figure 9 HEL Events Recorder Schematic

Vertical Acceleration	Amp #2 Output	8.08	mv/g	17.6R	17.6R
					51
Fore-aft Acceleration	Amp #3 Output	8.78	mv/g	ditto	
Side-side Acceleration	Amp #3 Output	8.78	mv/g	ditto	
				10K	
Elevation Reticle	Amp #6 Output	50	mv/mr		3.32K
Traverse Reticle	Amp #7 Output	50	mv/mr	ditto	
Traverse Rate	Integrator #2 Input	8	mv/mr/sec	None	
Elevation Rate	Integrator #1 Input	8	mv/mr/sec	None	
Cupola Gyro	Cable	8.0	mv/mr/sec	None	
Traverse Tach	Cable	14.3	mv/mr/sec	None	
Elevation Tach	Cable	15.4	mv/mr/sec	None	
				10K	
Lead In	Demodulator Output	80	mv/mr		3.32K
Track Speed	Intercom	1.50	pulse	None	

Figure 10 Additional Instrumentation

Visicorder #1

Instrumented Quantity	Desired Scaling	Actual Scaling	Polarity Physical	Polarity Recorder
Elevation Gun Gyro Position	2 mr/in	2.12 mr/in	Up	Left
Elevation Tachometer	1 rad/sec/in	0.99 rad/sec/in	Up	Left
Vertical Acceleration	1g/in	1g/in	Down	Right
Elevation Gunner Input	30 mr/sec/in	31.28 rad/sec/in	Up	Right
Elevation Reticle Position	10 mr/in	9.61 mr/in	Up	Right
Elevation Relative Angle	0.1 rad/in	0.099 rad/in	Up	Left
Traverse Relative Angle	Sine $\pm\pi/2 = \pm 3$ in	28 degrees/in		
Brow Pad Acceleration				
Helmet Acceleration				
Track Speed				

$15.4 \frac{\text{inches}}{\text{pip}}$ Forward Movement	Track Speed (mph)	Paper Speed (0.4 in/sec)	Paper Speed (2 in/sec)
	4	11.73 pips/in	2.34 pips/in
	5	14.67 pips/in	2.93 pips/in
	7	20.53 pips/in	4.11 pips/in
	12	35.20 pips/in	7.04 pips/in
	15	44.00 pips/in	8.80 pips/in

Figure 11 Visicorder #1

Visicorder #2

Instrumented Quantity	Desired Scaling	Actual Scaling	Polarity Physical	Polarity Recorder
Traverse Gun Gyro Position	2 mr/sec/in		Left	Right
Traverse Tachometer	1 rad/sec/in	0.98 rad/sec/in	Left	Right
Cupola Gyro	0.5 rad/sec/in	0.51 rad/sec/in	Left	Right
Fore-Aft Acceleration	1g/in	1g/in	Aft	Right
Side-Side Acceleration	1g/in	1g/in	Left	Right
Traverse Reticle Position	10 mr/in	10.64 mr/in	Right	Right
Computer Lead Angle	10 mr/in	11.78 mr/in	Right	Right
Traverse Gunner Input	30 mr/sec/in	41.10 mr/sec/in	Left	Left
Traverse Gun Gyro Rate	20 mr/sec/in	19.74 mr/sec/in	Left	Left
Track Speed	Same as Visicorder #1			

Figure 12 Visicorder #2

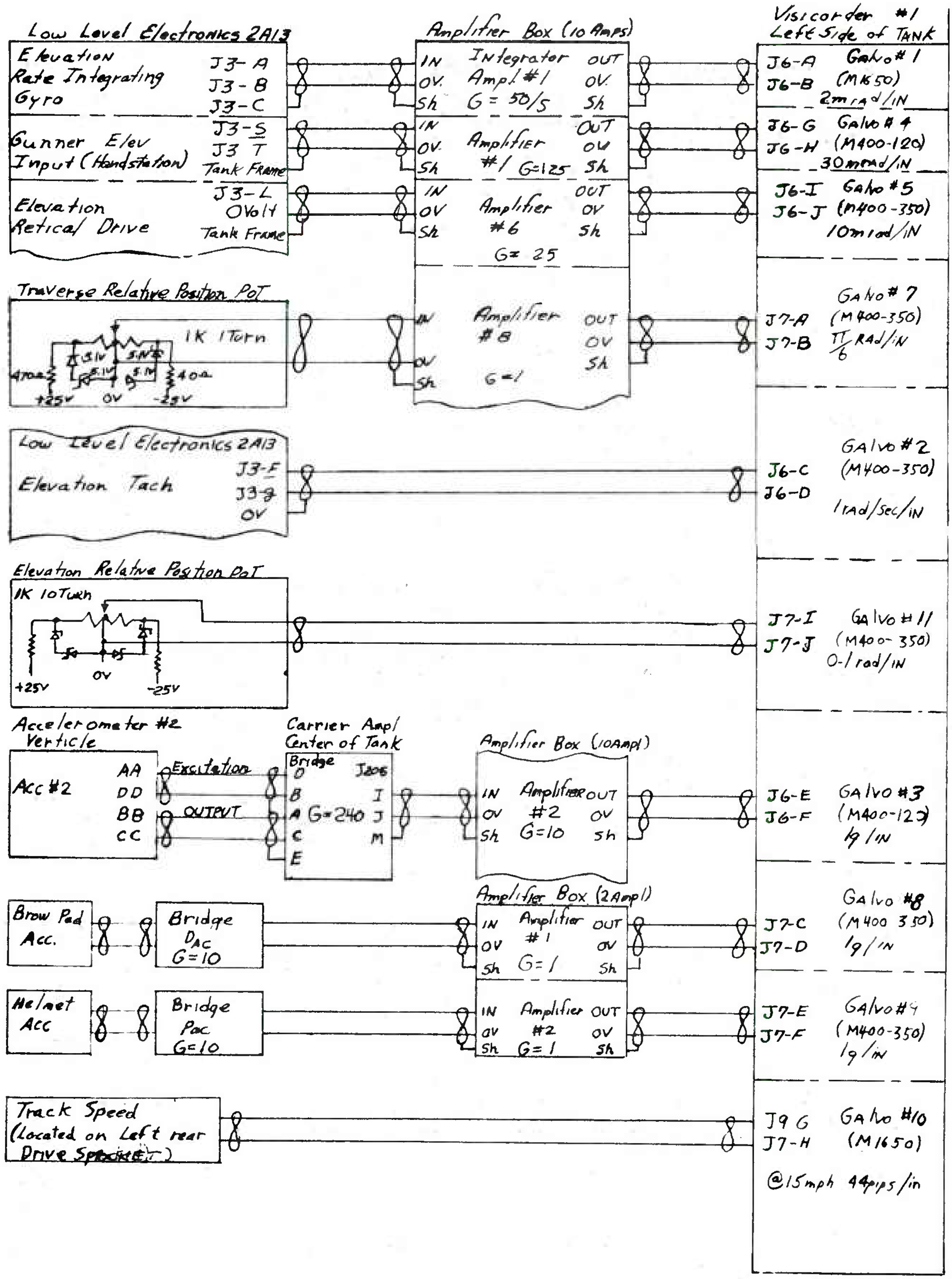


Figure 13 Instrumentation Schematic (Visicorder #1)

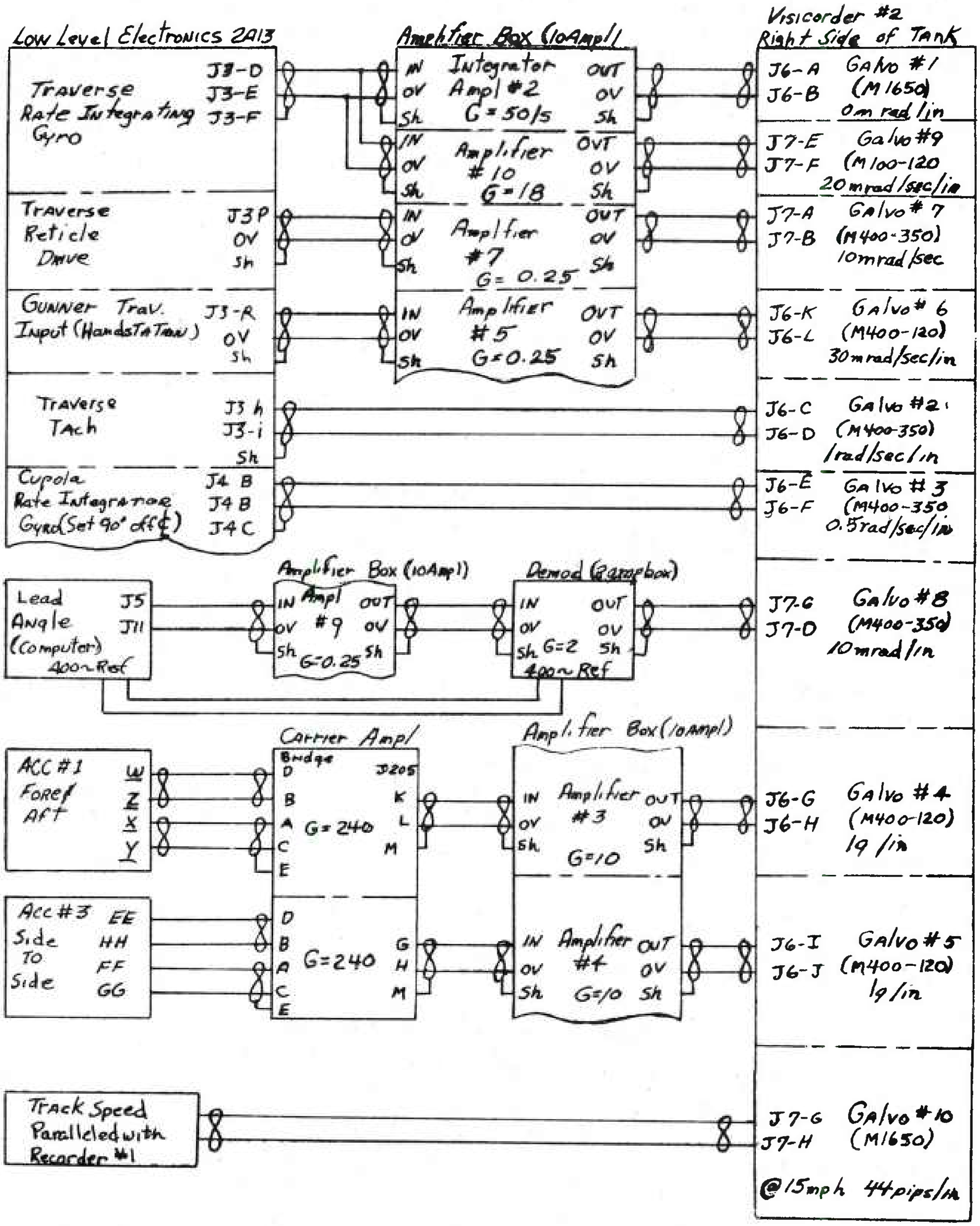


Figure 14 Instrumentation Schematic (Visicorder #2)

2.2.3.2 M60A1E2 Calibration Memo

M60A1E2 Calibration Memo
19 November 1970
5320-510

The accompanying tables for scaling and polarity are laid out such, that the signals are in the order of their zero position when looking at the Visicorder paper as it moves from right to left coming from the Visicorder.

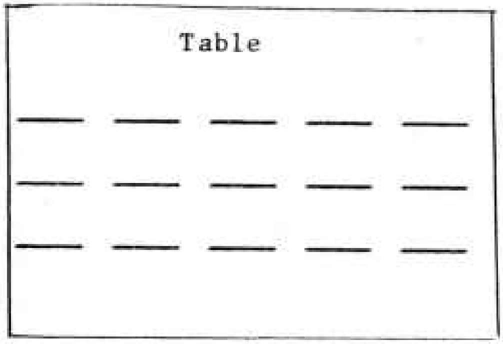


Figure 1

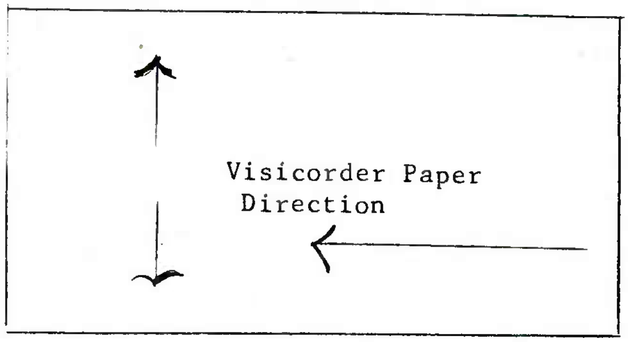


Figure 2

Mechanical polarities should be obvious for the most part. Elevation Reticle Position Up means that superelevation has been entered and the Bore Angle is greater than the Reticle Angle. Traverse Reticle Position Right and Computer Lead Angle Right both mean that the reticle leads the bore to the right when traversing a stationary target from left to right with LEAD IN activated.

Visicorder polarities are as shown in Figure 2 above.

Actual scalings are obtained by applying a voltage measured to 0.1% in lieu of the system signal. This voltage is then divided by the distance moved on the Visicorder Paper. This quotient is further divided by the original volts/inch figure which is calculated from the system transfer gradient and the desired scaling. The resultant quotient is then multiplied by the desired scaling to obtain the actual scaling.

Accuracy, to the greatest degree then, is affected by one's ability to read the Visicorder tracing. If one uses a scale with 1/50 inch marks, an estimate may be made to the nearest 1/100 of an inch of motion. Further, if a change of at least one inch is used for calibration, the reading error is 1%. This 1% plus the 0.1% input error plus 0.4% to allow for amplifier gain changes due to temperature and line variations, means that the scalings are accurate to ±1.5%. All of the above assumes that the system gradients as taken from transfer function schematics are without error.

The three-axis vehicle accelerometers are calibrated in the following manner. Two bubble levels are used to position the accelerometers in a non-sensitive axis and all nulling is completed. The accelerometer is then put in its positive sensitive axis using the two levels and the gain of the carrier amp is set to give 1g per inch. These accelerometers are mounted on the vehicle such that there exists some three-axis angular error. The error is shown in Figure 3.

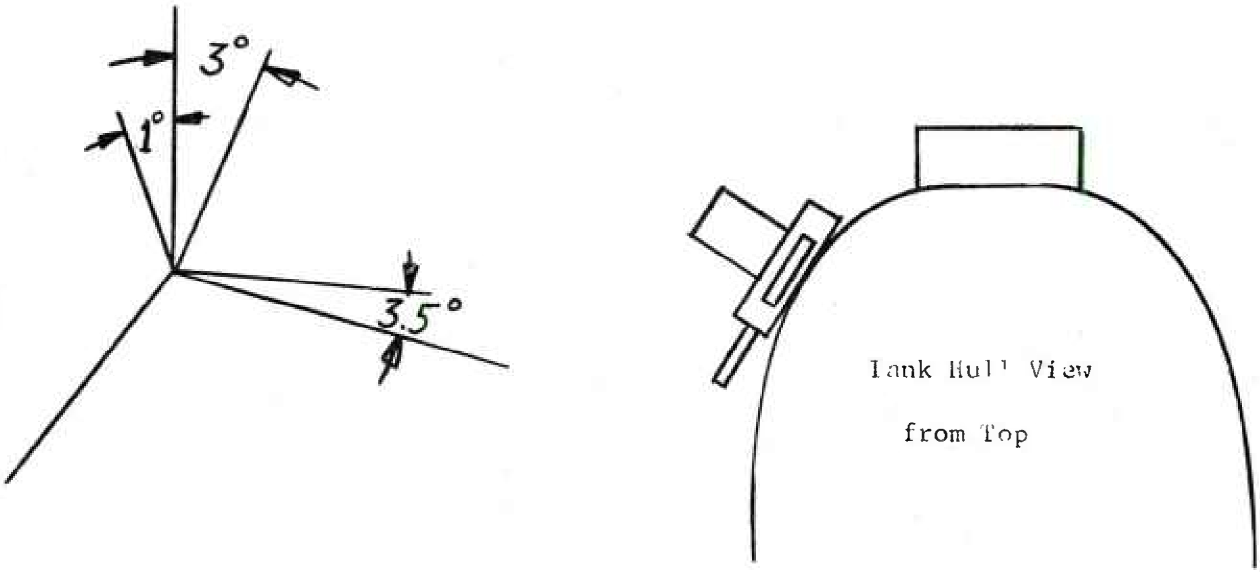


Figure 3

Fore-Aft	1	degree	(Pitch)
Side-Side	6	degrees	(Roll)
Yaw	3.5	degrees	

The fact that an auxiliary generator is being used to generate 115 volts 60 cycle can cause some error in paper speed. Since the frequency as seen on the panel meter on the generator is running about 1% high the paper speed will be correspondingly high.

The time line has a basic accuracy of ±2%. Add ±2% for ±1% change in line voltage from 117 V_{AC} and ±2% for ±50° ambient temperature change from +70°F.

Traverse Reticle Position and Computer Lead Angle were calculated using a computer solution with 1200 M range and 5 mr/sec traverse velocity. An auto collimator and grid board were used to optically measure the lead angle. This was assumed correct (recognizing errors in the computer solution) and was divided by the deflection on the Visicorder. The most significant error here would perhaps be the angular velocity as seen by the computer because the optical angle is read to the nearest tenth milliradian. The resolution error on the Visicorder is approximately 1/4%.

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/lmp

2.2.4 Discussion

The test results were indicative of apparent computer shortcomings. Lead was inserted for most runs to depict battle conditions even on straight courses and for stationary targets where the lead angle solution should have been zero, but instead of a zero lead angle in these situations, a lead angle was frequently introduced. The visual recordings and film taken for these tests confirmed that the stabilization system was providing a smooth track and an ability to stay on target. Since a lag tendency appeared during stationary tank-moving target tests, the computer was rechecked by Chrysler. The Chrysler representatives could not diagnose the problem without a more thorough check at Chrysler Defense in Detroit.

The analysis indicated that for a stationary tank at a 1500 meter range firing a 409/411E4 round at a 15 mph crossing target the computer lead should be 12.1 mils. Tests under these conditions resulted in a 10.5, 10.6, and 11.0 mil lead and indicated that our fire control system was performing with the above mentioned constant lag and outside of the 1.3 mil design tolerance for the 10.5 and 10.6 leads. For additional clarification, a documentary film is available on this test.

2.3 M60A1E2 Tank/Electro Hydraulic Gun Drives

2.3.1 Background

The first extension of HITPRO was to the M60A1E2 Tank with electro-hydraulic gun drives. The modeling for this extension was predominately that of developing a new DRIVE subroutine to simulate the standard M60A2 stabilization and gun drives. This DRIVE model is described in Section A.3 of Appendix A. The electro-hydraulic stabilization system was designed by Cadillac-Gage and manufactured by Chrysler. M60A1E2 was the experimental designation for the M60A2 Tank.

The purpose of this test was to evaluate the stabilization of the main weapon while firing on the move and to collect test data suitable for validation of the extended HITPRO model. The testing procedure, which will not be detailed to avoid redundancy, was quite similar to that described in section 2.2; however, the laser rangefinder was used in lieu of range markers. This change was significant to the firing sequence in that during ranging the gun could not be superelevated and that during range correction the reticle would be driven off target. This change is accounted for in the HITPRO validation, Section 4.

2.3.2 Instrumentation Plan

This Test Program was intended to provide basic data (on magnetic tape in analog format) of the M60A1E2 main weapon system for use with the "HITPRO" digital computer model. The program was conducted by the Tank Systems Laboratory of WECOM at the Aberdeen Proving Ground, beginning 1 November 1971. WECOM was provided with equipment and general support by both TECOM at APG and Chrysler Defense Engineering (CDE). The extent of the CDE participation is defined in Proposal H-1298.

2.3.2.1 General

The special equipment required was as follows:

a. To be supplied by CDE:

Signal Converter Unit

Harnessing

Three (3) pressure transducers and pipework

Turret-to-hull angle monitor

b. To be supplied by TECOM:

Three (3) accelerometers to monitor vehicle motion

Two (2) accelerometers - roadwheels motion

Drive sprocket monitor

Telemetry System

All CDE sensors were routed via the Signal Converter Unit to the telemetry, but all TECOM supplied equipment was routed directly. All hull mounted equipment was routed via the hull-to-turret slip ring, paragraph 2.3.2.6. The interface between the Signal Converter Unit and the telemetry system is specified in paragraph 2.3.2.3.

2.3.2.2 Channels of Information

The channels of information required from the test program are defined in Figure 15. A description of the required variable is given and its origin within the vehicle system. Column (4) assigns responsibility of the channel to TECOM or CDE and column (5) names the equipment from which it is derived, i.e., the Cadillac Gage amplifiers, missile tracker or special instrumentation sensor.

Figure 16 gives a schematic diagram of a typical instrumentation channel. Column (6) of Figure 1 defines the required overall gain from system variable to V_{DC} on tape (K V_{DC}/unit), column (7) defines the allowable tolerance on this gain, column (8) gives the range of input signal required to be monitored and column (9) verifies the allowable resolution.

Figure 17 assigns nominal gains and tolerances to the various elements of Figure 16. In many cases the stack-up of tolerances will exceed the requirement of overall accuracy and provision will be made for special calibration procedures discussed in paragraph 2.3.2.4.

The bandwidth requirement is that the response shall be flat to within ± 3.0 db from 0.0 Hz up to a frequency, f Hz, where f is defined as

$$fb \leq f \leq 100 \text{ Hz}$$

above 100 Hz, the response should roll off at $\geq$ 20 db/decade. fb is specified in column (10) of Figure 15.

2.3.2.3 Interface, Signal Converter Unit of Telemetry

The instrumentation system gains of Figure 16 have been chosen to give a full scale output of approximately ± 50 m V_{DC} at the interface. All signals to be D.C. or low frequency. The following requirements should be met at the interface.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
NO.	CHANNEL DESCRIPTION	UNITS	RESPON-SIBILITY	SOURCE	GAIN	TOL.	RANGE	RESOLU-TION	BAND-WIDTH fb	CAL.
					(V_{DC}/Unit)	(%)	(Units)	(% F.S.)	(Hz)	(Units)
1	Hull yaw rate (main azimuth hull gyro)	deg/sec	CDE	CAD-GAGE	0.1	± 6.0	± 25.0	1.0	50.0	+ 25.0
2	Turret pitch rate (main elevation hull gyro)	deg/sec	CDE	CAD-GAGE	0.1	± 6.0	± 25.0	1.0	50.0	+ 25.0
3	Turret roll rate (cupola EL hull gyro)	deg/sec	CDE	CAD-GAGE	0.1	± 6.0	± 25.0	1.0	50.0	+ 25.0
4	Azimuth Gun Rate (main AZ reference gyro)	deg/sec	CDE	CAD-GAGE	0.5	± 6.0	± 5.0	1.0	50.0	+ 5.0
5	Elevation Gun Rate (main EL reference gyro)	deg/sec	CDE	CAD-GAGE	0.5	± 6.0	± 5.0	1.0	50.0	+ 5.0
6	Azimuth rate command (main AZ handle amp)	deg/sec	CDE	CAD-GAGE	0.5	± 6.0	± 5.0	1.0	50.0	+ 5.0
7	Elevation rate command (main EL handle amp)	deg/sec	CDE	CAD-GAGE	0.5	± 6.0	± 5.0	1.0	50.0	+ 5.0
8	Turret-to hull angle ( ) (special monitor)	deg.	CDE	CAD-GAGE	0.025	± 5.0	±100.0	1.0	20.0	+100.0
9	Gun-to-turret angle ( ) (Elevation synchro)	deg	CDE	CAD-GAGE	0.1	± 5.0	±100.0	1.0	20.0	+ 25.0
10	Azimuth position error (main AZ integrator)	mil.	CDE	CAD-GAGE	0.1	± 5.0	± 25.0	1.0	20.0	+ 25.0
11	Elevation position error (main EL integrator)	mil.	CDE	CAD-GAGE	0.1	± 5.0	± 25.0	1.0	20.0	+ 25.0
12	Azimuth reticle position (Super lead)	mil.	CDE	CAD-GAGE	0.1	5.0	± 25.0	1.0	50.0	+ 25.0
13	EL reticle position (Super elevation)	mil.	CDE	CAD-GAGE	0.1	5.0	± 25.0	1.0	50.0	+ 25.0

Figure 15 Channel Specifications

(1) NO.	(2) CHANNEL DESCRIPTION	(3) UNITS	(4) RESPON-SIBILITY	(5) SOURCE	(6) GAIN	(7) TOL.	(8) RANGE	(9) RESOLU-TION	(10) BAND-WIDTH fb	(11) CAL.
					(V_{DC}/Unit)	(%)	(Units)	(% F.S.)	(Hz)	(Units)
14	Turret vertical accel.		TECOM	Accel.	0.5	± 5.0	± 5.0	1.0	50.0	
15	Turret fore-and aft accel.		TECOM	Accel.	1.25	± 5.0	± 2.0	1.0	50.0	
16	Turret traverse accel.		TECOM	Accel.	1.25	± 5.0	± 2.0	1.0	50.0	
17	Left roadwheel accel.		TECOM	Accel.	0.25	± 5.0	±10.0	1.0	50.0	
18	Right roadwheel accel.		TECOM	Accel.	0.25	± 5.0	±10.0	1.0	50.0	
19	Drive sprocket monitor		TECOM	Sensor						
20	Azimuth control torque (motor diff. pres)	psid	CDE	Trans-ducer	0.001	±10.0	±2500		50.0	+ 2500
21	Elevation control force (actuator diff. pres)	psid	CDE	Trans-ducer	0.002	±10.0	±1250		50.0	+ 2000
22	Hydraulic supply pres. (reference pres)	psig	CDE	Trans-ducer	0.0025	±10.0	+1500 +2500		50.0	+ 2000
23	Azimuth servo (3rd stage spool position)	inch	CDE	CAD-GAGE	10.0	± 7.0	0.25		50.0	+ 0.25
24	Elevation servo (3rd stage spool position)	inch	CDE	CAD-GAGE	10.0	± 7.0	0.25		50.0	+ 0.25
25	AZ handle deflection (Gunner's handle LVDT)	deg.	CDE	CAD-GAGE	0.0333	± 7.0	±75.0		50.0	+ 75.0
26	EL handle deflection (Gunner's handle LVDT)	deg.	CDE	CAD-GAGE	0.1	± 7.0	±25.0		50.0	+ 25.0
27	Main AZ reference demod.	V_{DC}	CDE	CAD-GAGE	0.1	± 5.0	±25.0	1.0	50.0	+ 25.0
28	Main EL reference demod.	V_{DC}	CDE	CAD-GAGE	0.1	± 5.0	±25.0	1.0	50.0	+ 25.0
29	Main AZ hull demod.	V_{DC}	CDE	CAD-GAGE	0.1	± 5.0	±25.0	1.0	50.0	+ 25.0
30	Main EL hull demod.	V_{DC}	CDE	CAD-GAGE	0.1	± 5.0	±25.0	1.0	50.0	+ 25.0
31	LOS error in Azimuth (Missile tracker)	m rad	TECOM	Missile Tracker		± 5.0		1.0	20.0	
32	LOS error in Elevation (Missile tracker)	m rad	TECOM	Missile Tracker		± 5.0			20.0	

Figure 15 (continued) Channel Specifications

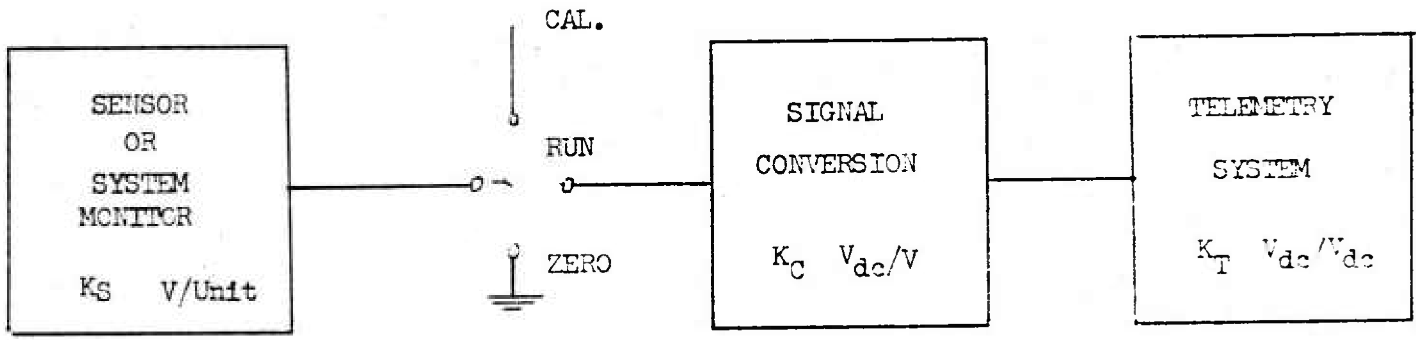


Figure 16 Schematic of a Typical Instrumentation Channel

CHANNEL NO.	SENSOR		SIGNAL CONV.		TELEMETRY		CHANNEL NO.	SENSOR		SIGNAL CONV.		TELEMETRY	
	GAIN	TOL.	GAIN	TOL.	GAIN	TOL.		GAIN	TOL.	GAIN	TOL.	GAIN	TOL.
	(V/Unit)	(%)	(V_{dc}/V)	(%)	(V_{dc}/V_{dc})	(%)		(V/Unit)	(%)	(V_{dc}/V)	(%)	(V_{dc}/V_{dc})	(%)
1 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	20*		± 3.0		± 3.0	50.0	5.0
2 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	21*		± 3.0		± 3.0	50.0	5.0
3 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	22*		± 3.0		± 3.0	50.0	5.0
4 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	23 a	30.0	± 5.0	0.00667	± 3.0	50.0	5.0
5 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	24 a	30.0	± 5.0	0.00667	± 3.0	50.0	5.0
6 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	25 a	0.125	± 5.0	0.00933	± 3.0	50.0	5.0
7 a	0.1	± 5.0	0.02	± 3.0	50.0	5.0	26 a	0.384	± 5.0	0.00521	± 3.0	50.0	5.0
8*		± 2.0		± 3.0	50.0	5.0	27	1.0		0.0020	± 3.0	50.0	5.0
9 a	0.22	± 2.0	0.0091	± 3.0	50.0	5.0	28	1.0		0.0020	± 3.0	50.0	5.0
10*	0.5	± 2.0	0.004	± 3.0	50.0	5.0	29	1.0		0.0020	± 3.0	50.0	5.0
11*	[illegible]	± 2.0	0.004	± 3.0	50.0	5.0	30	1.0		0.0020	± 3.0	50.0	5.0
12*	0.762	± 2.0	0.00263	± 3.0	50.0	5.0	31	To be Decided					
13*	0.762	± 2.0	0.00263	± 3.0	50.0	3.0	32	by TECOM					
14													
15													
16		To be Decided											
17		by TECOM											
18													
19													
						NOTE:	Sensors marked						
							(a) are 400 Hz excited and (*) will be specially calibrated (see paragraph						

Figure 17 Channel Component Specifications

a. Telemetry Input Impedance > 40 K Ω

b. Differential inputs to telemetry to isolate grounds, common mode voltage < 10 V_{DC}.

c. Overload voltages at the interface not to exceed ± 700 m V_{DC}, either transiently or steady state.

d. Shield to be grounded at the telemetry end.

e. High frequency noise levels at the interface (i.e., from demodulation, etc.) to be less than 1% of reading.

f. Provision will be made to select up to any 22 channels of the 24 channels available from the Signal Converter Unit.

2.3.2.4 Calibration

In order to obtain good accuracy on recorded data, three calibration techniques will be used - applies to CDE furnished items only. TECOM is responsible for ensuring accuracy of their own equipment. Calibration Procedures will be written where appropriate.

2.3.2.4.1 Pre-Test Program Calibration

This will be accomplished before delivery of hardware to APG and during the two week checkout and calibration period. This calibration will include:

a. All CDE supplied special instrumentation sensors.

b. All instrumentation channels in the Signal Converter Unit; against the requirements of Figure 17.

c. Scaling on the Cadillac Gage integrators (V_{DC}/mil).

d. F.C.S. reticle positions (V_{DC}/mil).

e. Gunner's handle amplifier non-linear gain characteristics (V_{RMS}/V_{RMS} and V_{DC}/V_{RMS} - handle LVDT gains will be assumed to be within specifications).

f. The third stage spool and gyro will be assumed to be within specifications for nominal supply voltage.

g. Elevation synchro.

2.3.2.4.2 Pre-Run Calibration

Prior to each vehicle run of the Test Program the instrumentation telemetry system will be operated with

a. Inputs to all channels grounded.

b. Known input levels (defined in column (11) of Figure 15). These levels will be scaled against the 26 V_{RMS} 400 Hz and + 28 V_{DC} supplies for channels monitoring sensors where gain is a function of these supplies. These signals (each of approximately 10 seconds duration) will provide zero to positive CAL. signals on the tape against which the data recorded during the run may be scaled.

2.3.2.4.3 Pre-Set Program

It may be desirable to repeat some of the pre-set program calculations during the duration of the program - on a daily or weekly basis.

2.3.2.5 The Signal Converter Unit

All CDE supplied channels will be routed through this unit.

2.3.2.5.1 The channel gains and accuracies will be as specified in Figure 17.

2.3.2.5.2 The channel frequency characteristics shall satisfy the over-all bandwidth requirements of Figure 15 and paragraph 2.3.2.2 and the noise requirements of paragraph 2.3.2.3.

2.3.2.5.3 The calibration requirements of paragraph 2.3.2.4 will be satisfied.

2.3.2.5.4 The interface requirements with the telemetry system of paragraph 2.3.2.3 will be satisfied.

2.3.2.5.5 All inputs to the Signal Converter Unit will be compatible with the respective sensors and Cadillac Gage amplifiers.

2.3.2.5.6 Where necessary, protection will be afforded the Cadillac Gage amplifiers or sensors from possible malfunctions occurring within the Signal Converter Unit.

2.3.2.5.7 All conversion from the 400 Hz carrier signals shall be phase sensitive demodulated.

2.3.2.5.8 Use may be made of the Cadillac Gage power supplies. Currents drawn not to exceed the equivalent of 4.0 watts of the 400 Hz supply, 5.0ma of the 28 V_{DC} supply and 2.0ma from the 15 V_{DC} supply - for either of the azimuth or elevation power packs. If necessary, the design may assume that the 26 V_{RMS} 400 Hz supplies will be held to ± 5%, so long as provision is made for checking and adjustment during the test program. Other supplies will be as per specification.

2.3.2.5.9 Mechanical Requirements

The Signal Converter Unit should be of rugged construction and designed to be located above the radio behind the commander's station. Provision shall be made for it to be securely fixed in position. All switches, converters and adjustments should be within easy reach when the unit is secured. Consideration should be given to maintenance, access and provision of spaces. Consideration will be given to vibration testing of the unit in addition to normal bench testing. The connectors supplied by TECOM will be used for mating with the telemetry system (see paragraph 2.3.2.10).

2.3.2.5.10 Drawings, circuit diagrams and calibration adjustment and checkout procedures will need to be documented.

2.3.2.6 Harnessing

2.3.2.6.1 Signal Converter Unit to Telemetry System - This harness is the responsibility of TECOM and will terminate in plugs that mate with the Signal Converter Unit.

Signal hot - pin #2
Signal ground - pin #3

Up to 22 channels to be available at one time.

2.3.2.6.2 All harnessing into connecting CDE supplied equipment and the Cadillac Gage amplifiers will be checked as satisfactory prior to delivery to APG.

2.3.2.6.3 Hull-to-Turret Slip Ring Harnesses - T-harnesses will be supplied by CDE, one either side of this slip ring. Provision will be made to T into each of the 20 spare channels presently available. Leads will be long enough to extend into the driver's compartment on the hull side and approximately 4 feet on the turret side. Plugs and sockets already supplied to CDE by TECOM will be connected to carry channels (17) and (18) of Figure 15 - four wires for each channel. Channel (19) will require two wires. Coding will be provided.

2.3.2.6.4 Harnesses interconnecting TECOM supplied equipment shall be the responsibility of TECOM.

2.3.2.7 Pressure Transducers

These transducers shall meet the requirements of Figure 15 and 17 and the bandwidth requirements of paragraph 2.3.2.2. Pipework will need to be fabricated to enable monitoring of:

a. Channel (20) - differential pressure across the main azimuth hydraulic motor.

b. Channel (21) - differential pressure across the main elevation hydraulic actuator.

c. Channel (22) - gauge pressure of the hydraulic power supply - reference pressure.

For the differential pressure transducers, pipe length and diameters should be held to a minimum so as not to significantly increase the motor and actuator entrained volumes.

2.3.2.8 Turret-To-Hull Angle Monitor

This device shall meet the requirements of Figure 17 and paragraph 2.3.2.2. If the dial indicator drive is used, provision should be made to change from the monitor to the dial indicator easily - or preferably have both functioning together.

2.3.2.9 Accelerometers

The turret mounted accelerometers should be aligned vertically, along the gun axis (gun elevation angle zero degrees) and normal to the gun axis in the horizontal plane - to within a 5 degree curve. The accelerometer block shall be located on the outer left side of the turret - actual location to be determined.

The roadwheel accelerometers will be mounted on the hubs of the left and right front roadwheels, i.e., the first wheel to hit a bump - and will be orientated in the vertical direction ± 10 degrees.

The accelerometers will satisfy the requirements of Figures 15 and 17 and paragraph 2.3.2.2.

2.3.2.10 Telemetry

The telemetry will be required to provide up to 22 channels simultaneously in addition to one voice and one timing channel. Data will be required as analog signals recorded on magnetic tape (details of the tape are to be specified). Display of a selected number of channels on pen recorder during the test runs will be required and the capability of playing back any of the channels immediately after a run will also be needed.

A channel bandwidth in excess of 500 Hz is assumed and resolution better than 1% of full scale. The gain and accuracy requirements are given in Figures 15 and 17.

2.3.3 Calibration Procedures

2.3.3.1 Calibration procedure - AC/DC Boards

Refer to the monitor plug and potentiometer identification chart.

a. Check Board #7 - pins 1 and 2, 7 and 8 for level of 400 Hz AC voltage; note values (approximately 26 VAC).

b. Check Board #15 for proper D.C. levels (± 1 VDC).

c. Check Board #16 for calibration levels when CAL/RUN switch is in HI and LOW calibration position. A.C. levels approximately 26 VAC: D.C. levels approximately 26 VDC.

d. Set calibration pots for these levels ± 1% (CAL SW-HIGH); monitor plugs #1 and 2 or 6 and 7: AC Boards; 2 and 3 or 3 and 4: DC Boards.

NOTE: AC levels listed are for Board #7 400 Hz voltages of 26.0 V_{AC}. If valves are different, increase or decrease these calibration levels by the same %. (or adjust Cadillac Gage power supplies for 26.0 V_{AC} at Board #7).

Board #	CH #		HIGH CAL LEVEL
1	1	AZ.	2.5 VAC
1	4	AZ.	0.5 VAC
2	6	AZ.	0.5 VAC
2	23	AZ.	7.5 VAC
3	25	AZ.	9.4 VAC
4	2	EL.	2.5 VAC
4	5	EL.	0.5 VAC
5	7	EL.	0.5 VAC
5	24	EL.	7.5 VAC
6	26	EL.	9.6 VAC
6	9	EL.	5.5 VAC
8	10		12.5 VDC
8	12		19.0 VDC
9	27		25.0 VDC
9	29		25.0 VDC
10	3		5.5 VDC
10	11		12.5 VDC
11	30		25.0 VDC
11	28		25.0 VDC
12	13		19.0 VDC
13	22 (Pins 3 and 4		1.0 VDC

e. After calibration pots are adjusted, the D.C. voltage levels on the output monitor plugs of each board should indicate a difference of 50 + 10 mv D.C. between the high calibration and low calibration switch positions.

2.3.3.2 Hydraulic Pressure Boards #13 and #14

a. Note the hydraulic supply pressure reading on Board #14 pins 3 and 4 - calibration switch in run. Approximately: 1 VDC.

b. In power mode, note the steady valve reading on Board #13 plug 2 and 3: 0 ± 10 mv. If not, adjust Allen set screw "Z" on transducer demodulator (located near azimuth transducer).

c. Put the turret gear lock in lock position. In power mode, depress the palm switches and rotate the handles full CW and CCW while noting the highest steady readings on Board #13 plug 2 and 3. The difference between the CW and CCW levels should be equal to (± 1%) the level obtained in Step a. If not, adjust Allen set screw "S" on transducer demodulator (near azimuth transducer).

d. For elevation transducer, depress and elevate gun against the stops for maximum steady readings on Board #14 plugs 3 and 4. Difference should be equal to four times ± 1% the value in Step a. If not, adjust Allen set screw "S" on the transducer. The levels should be of equal magnitude ± 40 mv. If not, adjust the Allen set screw "Z" on the transducer.

2.3.3.3 Setting Up The Alternate Lead Solution

The "alternate" lead solution uses the output of the azimuth handle amplifier (commanded rate) from which to compute the required lead; as opposed to the "conventional" solution which uses the Fire Control System rate gyro. This setting-up procedure is intended to match the alternate solution against the conventional solution as reference. This is required because the alternate solution is inherently more inaccurate, statically. Both null and gain adjustments are required.

Stabilization System	-	Stabilized and nulled out
Fire Control System	-	On, boresight, range 1500 m
Lead Solution Switch	-	"ALTERNATE"

a. Null:

Measure the output of the Signal Converter Unit with respect to the Fire Control ground -

SCU Board #16, monitor plug #3 - Handle Lead Solution

SCU Board #16, monitor plug #1 - FCS Ground

Adjust the null potentiometer (No. 1, Board #16) to give 0 ± 10 m V_{DC} at this point.

b. Gain:

Input: 400 Hz signal across SCU Board #3, monitor plugs #1 and 2 - HDL AMP INPUT

Monitor: SCU Board #1, plug #5 - Azimuth reference gyro

Lead Solution Switch - CONVENTIONAL

Adjust the 400 Hz signal to give 20 ± 10 m V_{RMS} at the reference gyro output (4 ± 2 mils/sec). Depress and release the lead solution trigger and note the azimuth reticle position output (SCU, Board #8, plug #5, V_{DC} with respect to ground, plug #3).

Reverse the phase of the 400 Hz input signal and repeat this measurement for the opposite rotation of the turret. Calculate the total reticle deflection for solutions for clockwise and counterclockwise turret rotations.

Lead Solution Switch - "ALTERNATE".

Repeat the above measurements for the alternate solution, ensuring that the achieved target rate is the same as before - to within 1 m V_{RMS}. Adjust the gain potentiometer of the Handle Lead Solution board (#16, pot. #2) to give the same overall reticle deflection as for the conventional solution.

2.3.3.4 Calibration Procedure For the Handle Amplifiers

Stabilization System - On, power mode

Introduce a variable 400 Hz signal to the input of the handle amplifier (output of the HDL LVDT), SCU:

	Azimuth	Elevation
Board #	3	6
Monitor Plug #	1 and 2	1 and 2

Measure the output of the handle amplifier, SCU:

	Azimuth	Elevation	
Board #	2	5	
Monitor Plug #	1 and 2	1 and 2	V_{RMS}
Monitor Plug #	3	3	V_{DC}

Measure the inputs required to achieve the outputs specified below: Measure also the instrumentation output in each case.

Azimuth: Output m V_{RM} = 10 ± 1, 40 ± 1, 150 ± 1, 250 ± 1.

Elevation: Output m V_{RMS} = 15 ± 1, 50 ± 1, 100 ± 1, 150 ± 1.

Repeat for the input reverse phase.

Deadband - with zero input note the output.

Slowly increase the input until the output changes by 0.5 m V_{RMS}. Record the input and repeat for reverse phase of the input.

The handle LVDT gains are to be assumed to be within specification.

Azimuth	0.125 ± 8%	V_{RMS}/degree
Elevation	0.384 ± 8%	V_{RMS}/degree

2.3.3.5 Electronics Conditioning Package Directory

[illegible] - MT 4400

MONITOR PLUG AND POTENTIOMETER IDENTIFICATION

CHRYSLER DEFENSE ENGINEERING

	BOARD NO.	DESCRIPTION	CHANNEL NO.	MONITOR PLUG NO. 1	2	3	4	5	6	7	8	9	10	11	POT. 1	POT. 2
	1	Azimuth Null Gyro	1	- INPUT -		OUTPUT	GND								CAL.	
	1	Azimuth Reference Gyro	4				GND	OUTPUT	- INPUT -							CAL.
	2	Azimuth HDL AMP	6	- INPUT -		OUTPUT	GND								CAL.	
	2	Azimuth Third Stage	23				GND	OUTPUT	- INPUT							CAL.
AC	3	Azimuth HDL LVDT	25	- INPUT		OUTPUT	GND								CAL	
	3	Spare	-				GND	OUTPUT	- INPUT -							CAL.
	4	Elevation Null Gyro	2	- INPUT -		OUTPUT	GND								CAL	
	4	Elevation Reference Gyro	5				GND	OUTPUT	- INPUT -							CAL.
	5	Elevation HDL AMP	7	- INPUT -		OUTPUT	GND								CAL	
	5	Elevation Third Stage	24				GND	OUTPUT	- INPUT -							CAL.
	6	Elevation HDL LVDT	26	- INPUT -		OUTPUT	GND								CAL.	
	6	Elevation Synchro (β)	9				GND	OUTPUT	- INPUT -							CAL.
	7	Azimuth Power Supply	-	hot (400 Hz) rtn		SW1	SW2									
	7	Elevation Power Supply	-					SW2	S-1	rtn (400 Hz) hot						
	8	Azimuth Integrator	10	OUTPUT	INPUT	GND									CAL	
	8	Azimuth Super Lead	12			GND	INPUT	OUTPUT								CAL.
	9	Azimuth Reference Demod.	27	OUTPUT	INPUT	GND									CAL.	
	9	Azimuth Null Demod.	29			GND	INPUT	OUTPUT								CAL.
	10	El. Cup Null Gyro	3	OUTPUT	INPUT	GND									CAL.	
DC	10	Elevation Integrator	11			GND	INPUT	OUTPUT								CAL.
	11	Elevation Null Demod.	30	OUTPUT	INPUT	GND									CAL	
	11	Elevation Reference Demod	28			GND	INPUT	OUTPUT								CAL
	12	Elevation Super Elevation	13	OUTPUT	INPUT	GND									CAL.	
	12	Spare	-			GND	INPUT	OUTPUT								CAL.
	13	Azimuth Diff. Pressure	20	OUTPUT	INPUT	GND									CAL.	
	13	EHD Supply Pressure	22			GND	INPUT	OUTPUT								CAL.
	14	Turret/ El Angle (α)	8	OUTPUT	INPUT	GND									CAL.	
	14	Elevation Diff. Pressure	21			GND	INPUT	OUTPUT								CAL.
	15	Azimuth D.C. Power Supply	-	+13V	+ 11V	GND	-13V									
	15	El. D.C. Power Supply	-					-13V	GND	+11V	+13V					
	16	HDL Lead Solution	-	FCS GND	INPUT	OUTPUT									NULL	GAIN
	16	Azimuth Cal. Supplies	-				D.C. Rtn	A.C. Rtn	D.C. Cal	A.C. Cal						
	16	Elevation Cal. Supplies	-								A.C. Cal	D.C. Cal	A.C. Rtn	D.C. Rtn		

CHANNEL NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	20	21	22	23	24	25	26	27	28	29	30
D.C. BOARD NO.	1	4	10	1	4	2	5	14	6	8	10	8	12	13	14	13	2	5	3	6	9	11	9	11

2.4 MICV-65/All Electric Gun Drives

2.4.1 Background

HITPRO II validation tests were conducted by the U.S. Army Weapons Command during the period of October through December 1972 at the Yakima Firing Center, Yakima, Washington. The objective of these tests was to collect data needed to validate and refine the HITPRO II digital computer simulation of a Rapid Fire Weapon System for Army vehicles. For test purposes, the HITPRO II math model uses the characteristics of a MICV-65 vehicle, a General Electric gun stabilization system, a HS820 20mm gun and a human gunner. The MICV-65 is shown in Figure 18. The General Electric Company's responsibility during these tests was to provide and maintain the stabilization system and to provide, install, calibrate, maintain and operate all vehicular instrumentation for these tests. The 25 tracks of magnetic tape data recorded for the first series of tests (called the standard tests) were to validate and refine the model in three of its four major areas. The quantities recorded are listed below.

<u>MICV-65 Vehicle</u>

a. Three orthogonal linear accelerations of the vehicle's turret.

b. Right and left track speeds.

c. Gun position relative to the hull and turret.

d. Turret pitch and hull yaw rates relative to space.

e. Turret pitch and roll angles.

f. Vertical motion of middle road wheel on both sides of the vehicle.

<u>General Electric Gun Stabilization System</u>

a. Gun velocity relative to space.

b. Motor currents.

c. Gun velocity relative to the hull and turret.

<u>Human Gunner</u>

a. Gunner's handstation inputs to the stabilization system.

b. Gunner's trigger pull.

Auxiliary data included a voice track, data start signal, tape speed reference signal and a timing signal to coordinate magnetic tape data with gun camera film data.

Figure 18 MICV-65 Vehicle

Further HITPRO II model refinements, mainly in the gun model area, were to be made by conducting the following five special tests to conclude the testing.

a. Profile of gun receiver motion during firing.

b. Vehicle reaction to gun firing.

c. Gun barrel whip during firing.

d. Gun recoil force during firing.

e. Backlash and windup of the elevation and traverse power drive gear trains.

2.4.2 General Description of Instrumentation

2.4.2.1 Magnetic Tape Recorder Characteristics

Instrumentation data recording was done by use of a Sabre V magnetic tape recorder supplied by U.S. Army Weapons Command, Rock Island Arsenal. This Sangamo Model 3614 recorder has the following characteristics:

a. IRIG FM intermediate-band with 120 through 1 7/8 ips speed range.

b. 28 track interleaved heads.

c. 40 KHz bandwidth at 120 ips with a linear reduction to 625 Hz at 1 7/8 ips.

d. FM reproduce at 1 7/8, 15 and 60 ips.

e. Tape Synchronous Control.

f. Remote Control Panel.

g. Operating temperature range of 5°C to 50°C (41°F to 122°F).

h. Power requirements of 26 to 30 V_{DC} or 22 to 26 V_{DC} at 20 amps continuous and 30 amps peak (5 sec).

This magnetic tape recorder is designed to be operated within a 40% frequency deviation of the FM carrier frequency. The maximum positive signal input to a track should cause the FM carrier frequency to increase by 40% while the maximum negative input causes the carrier frequency to decrease by 40%. A potentiometer control is provided on each track to adjust this signal level-frequency deviation condition.

2.4.2.2 Instrumentation - General Description

a. Operation - Test Data - Figure 19 is a functional block diagram of the instrumentation used for these tests. The signals recorded on magnetic tape indirectly come from the electrical outputs of the instrumentation sensors. The sensors used were rate gyros, vertical gyros,

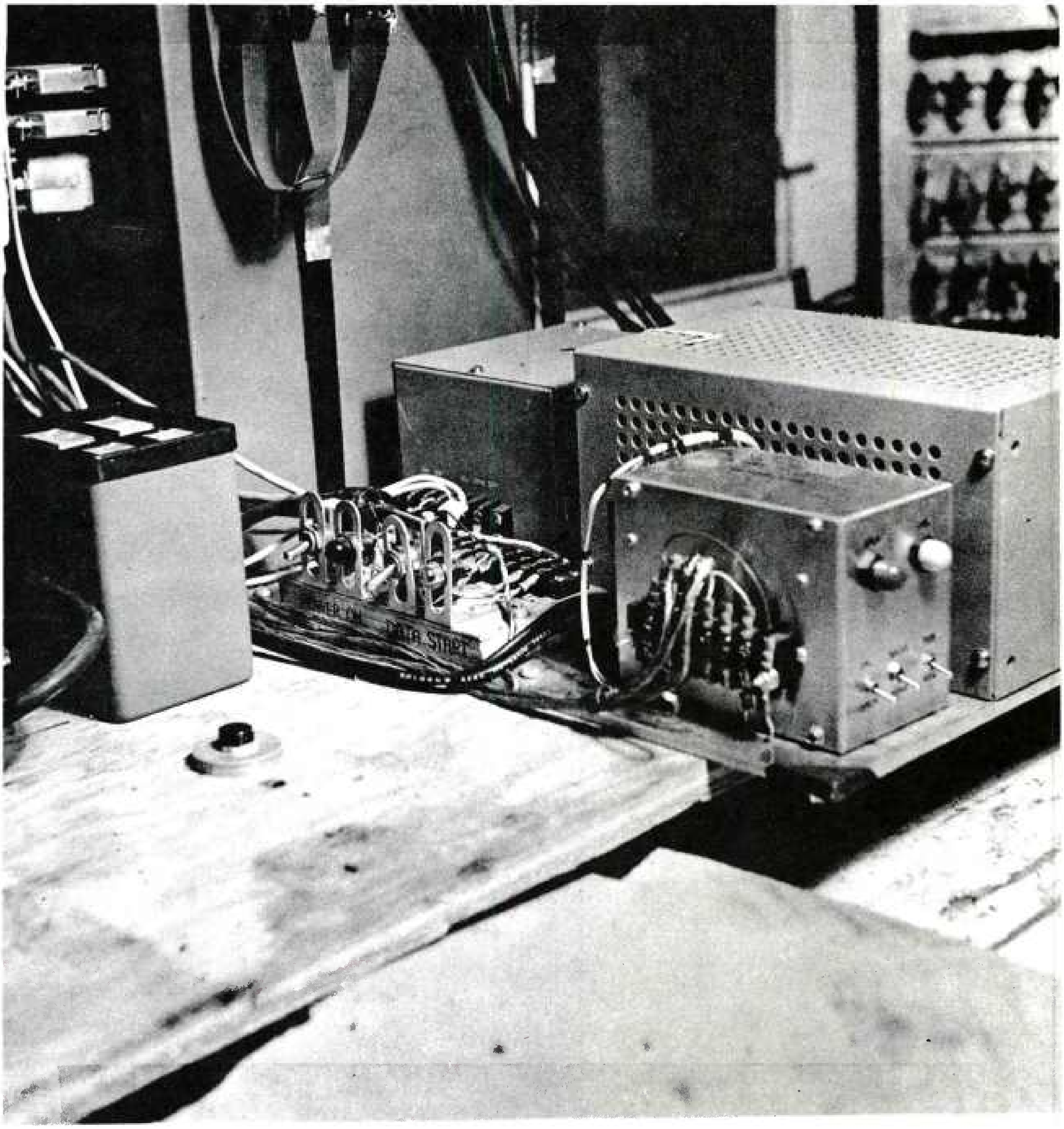


Figure 19 Vertical Gyro Power Supply and Electronics Box

accelerometers, tachometers, magnetic pickups, potentiometers and signals from the power drive electronics box. The sensor outputs are fed into instrumentation amplifiers for purposes of signal conditioning and the elimination of grounding problems between equipments.

Each amplifier output is connected, via the tape recorder's internal wiring, to a separate FM record board for each track. The record board contains a voltage-controlled oscillator (VCO) which is adjusted during the calibration procedure to produce a ±40% deviation of the FM carrier frequency at ± maximum input signal levels generated by the calibration box.

The frequency modulated output of the VCO passes to the record electronics which control the signal level to the record head and, subsequently, to the magnetic tape.

The reproduce heads and electronics combine to allow a playback of the recorded data, i.e., demodulated back to its original signal characteristics. A visicorder oscillograph was used in the field to verify that all 25 tracks of data were being recorded satisfactorily. This was a very important feature as it allowed interim field checkout of operation without waiting for a complete roll of magnetic tape to be sent to a processing center.

b. Calibration Procedure - The process of calibrating the tape recorder involves adjusting the FM record carrier center frequency and frequency deviation at specified levels of signal input. All calibration was done with the tape recorder operating at its maximum tape speed of 120 ips with a carrier center frequency of 216 KHz.

The FM record carrier center frequency is adjusted after shorting the signal input to each track and then using a potentiometer adjustment of each FM record board to adjust the center frequency to 216 KHz at a tape speed of 120 ips. This quantity was measured and verified by using a frequency counter.

A maximum positive signal input to each track is then applied and another pot adjustment on each record board is used to adjust for a new carrier frequency of 302.4 KHz which is 40% higher than the center frequency. In theory, the application of the maximum negative signal

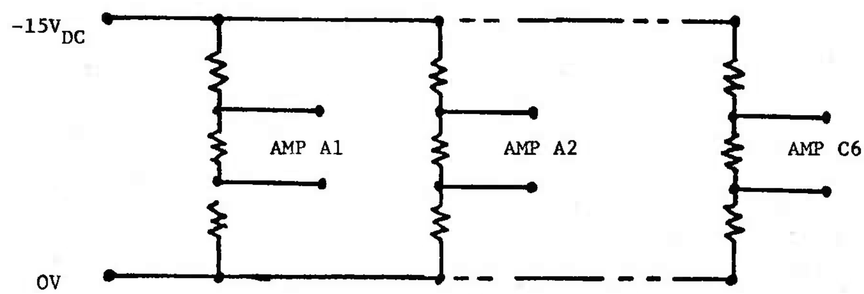


Figure 20 Calibration Box Schematic

should now cause the carrier frequency to shift to 129.6 KH . It was found that an error of about 1 to 2% would occur in the value measured on the frequency counter. This error translates into a 1.5 to 3% error in the desired frequency deviation.

An iterative procedure was then used to try to obtain a best fit of the three frequency values for one of the recording tracks. This procedure required 2 to 3 minutes with the resulting condition that all three values would be slightly deviated from their nominal values. The time involved in calibrating all tracks in this manner did not seem to be worth the effort. It was decided that the carrier would be adjusted to 216 KHz at OV input and 302.4 KHz at maximum positive input. All errors would be allowed to accumulate at the negative frequency deviation. This produces a slight unbalance in the positive and negative calibration signals appearing on the tape, but it is a known condition that can be corrected during the data processing.

The previous procedure involved the adjustment of each FM record board without recording any data on the tape. When the calibration signals are being recorded it was required that all signals be recorded simultaneously. This required the use of a calibration box whose schematic is shown in Figure 20.

A ladder network was used across a floating 15 V_{DC} power supply. The output across each center resistor was trimmed to a value that would produce the same instrumentation amplifier output as would the maximum output from the instrumentation sensor.

The calibration box is shown in Figure 21. Toggle switches on the face of the box were used to apply different signal levels to the tape recorder. With the left switch in the ZERO position, the power supply connection to the ladder network was replaced by a short circuit which results in a OV input to the instrumentation amplifiers and tape recorder. Toggle switches in the VALUE and POS positions connects the power supply to produce negative outputs at the center resistors of the ladder network. These signals into inverting instrumentation amplifiers produce maximum positive inputs to the tape recorder with a resulting +40% frequency deviation. Toggle switches in the VALUE and NEG positions produce the -40% frequency deviation.

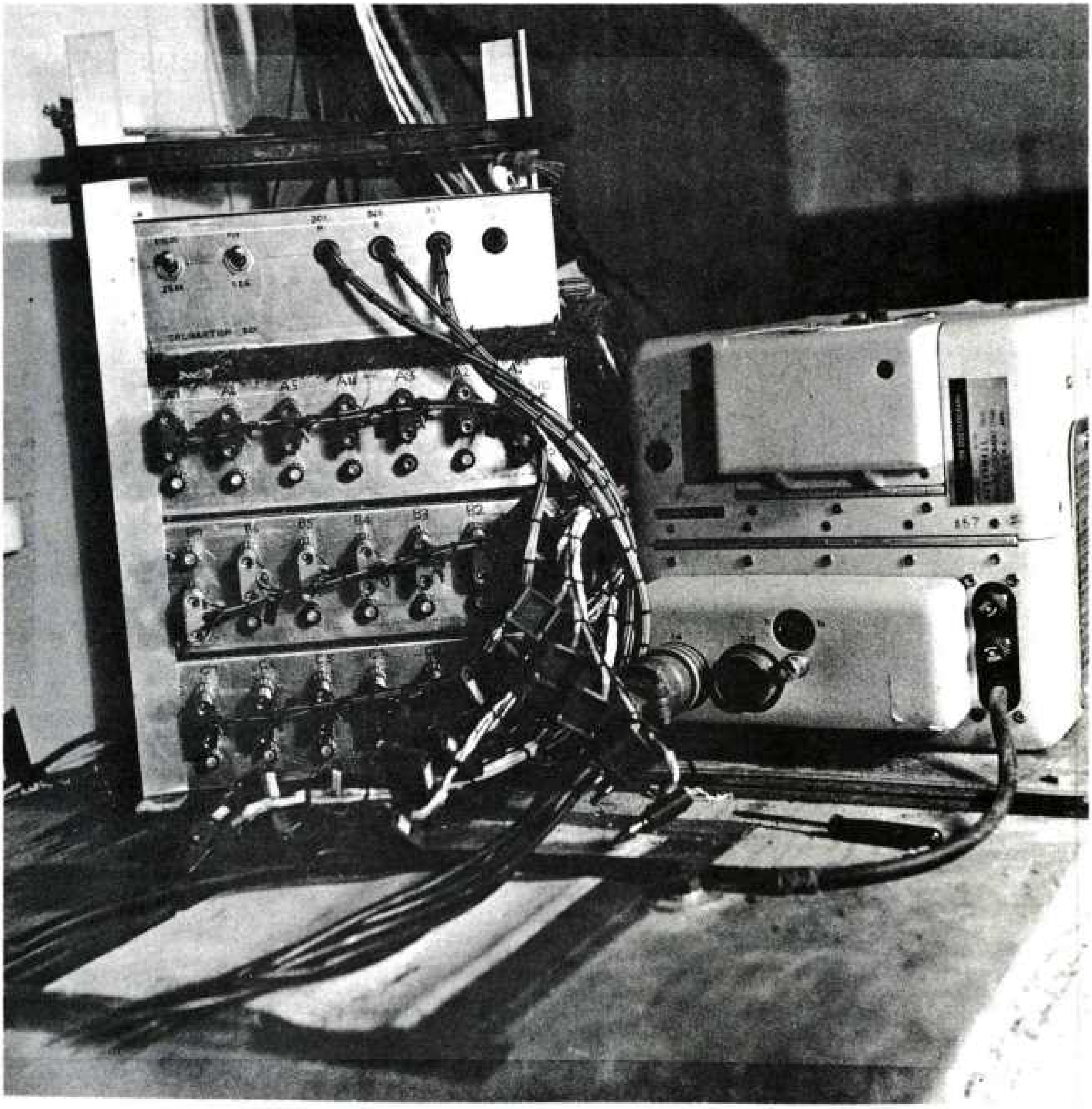


Figure 21   Calibration Box, Instrumentation Amplifier
Boxes and Visicorder

2.4.2.3 Data Limitations

The outputs of the sensors were to be recorded while the vehicle was being operated under a widely varying set of conditions. Some data was collected while the vehicle was stationary while other data was obtained with the vehicle being driven at various speeds up to 15 mph over several types of terrain: smooth gravel, zig-zag and bump courses.

This varying conditions present a problem in trying to obtain high quality data. The approach taken was to use our experience to assume the maximum physical input to each sensor for the duration of the field testing, e.g., maximum hull yaw rate would be 60 deg/sec on a 15 mph zig-zag run. From this type of assumption followed the maximum electrical output of each sensor. When this signal appears at the tape recorder input, it should produce a 40% deviation of the FM carrier in order to record the full signal without saturation.

If the vehicle is now driven on a relatively straight path to the target, very low hull turning rates will result. Under this condition the instrumentation is not sensitive enough to record the lower signal level to a full 40% deviation of the FM carrier. This could have been accomplished by recalibrating many tracks of the recorder for each different type of test condition. Such an effort by the on-site instrumentation operator would have resulted in an excessive amount of lost test time and also tend to increase operator error.

In summary, when a signal is relatively large (in its expected range of values) then it is recorded with the fullest possible fidelity. When it is very small (less than 10% of its maximum value) then it must be relegated to the noise level of events.

2.4.3 Standard Tests

2.4.3.1 Math Model of Stabilization System

A transfer function block diagram of the MICV-65 stabilized power drives has previously been published in the Cost/Performance Study report. This math model shows the servo loop crossover frequencies of the current, tach and gyro feedback loops which dictate the performance of the drives. The electronics box presently installed in the MICV-65 vehicle uses different individual amplifier gains but mechanizes the same loop crossovers as previously published. Since the standard tests at Yakima present data as physical quantities (i.e., position, velocity, acceleration, motor currents), the existing math model may again be used in order to validate the model with the results of the standard tests.

2.4.3.2 Test Instrumentation

Signals from the sensors and servo's electronics box, located in the turret, were routed to two connectors located on the back of the turret. The connectors provided a quick-disconnect of the instrumentation cables whenever the turret covers were closed for overnight storgae or travel between test courses. The cables then came out of the turret, passed through a field version of a slip ring shown in Figure 22, traveled four feet above the rear deck to avoid gun entanglement and proceeded into the passenger compartment.

Detailed descriptions of each tape recorder track are now presented along with any field problems encountered during the tests. The general approach taken with regard to filtering of signals was to record all data in its raw, unfiltered state. In this manner all physical information would be captured on magnetic tape. On subsequent playback, the data analyst would have the option of using the raw data or using filters, at his discretion, to remove unwanted frequency components. A few exceptions were made to the general approach where judgement indicated that filtering would improve the recorded signal without any loss of important physical data.

TRACK 1 VOICE CHANNEL

Track 1 was equipped with a hand-held microphone to record the instrumentation operator's comments. A headset was provided to listen to the playback of the recorded comments. Typical commentary involved the following items:

a. Run number
b. Type of course
c. Vehicle speed
d. Identify gunner
e. Date, time of day and weather conditions
f. Gun firing sequence

Figure 22 Slip Ring for Instrumentation Cables

g. Tape speed

h. Problems encountered and modifications made

i. Calibration procedure.

TRACK 2 TURRET ACCELERATION (SIDE-SIDE)

TRACK 3 TURRET ACCELERATION (FORE-AFT)

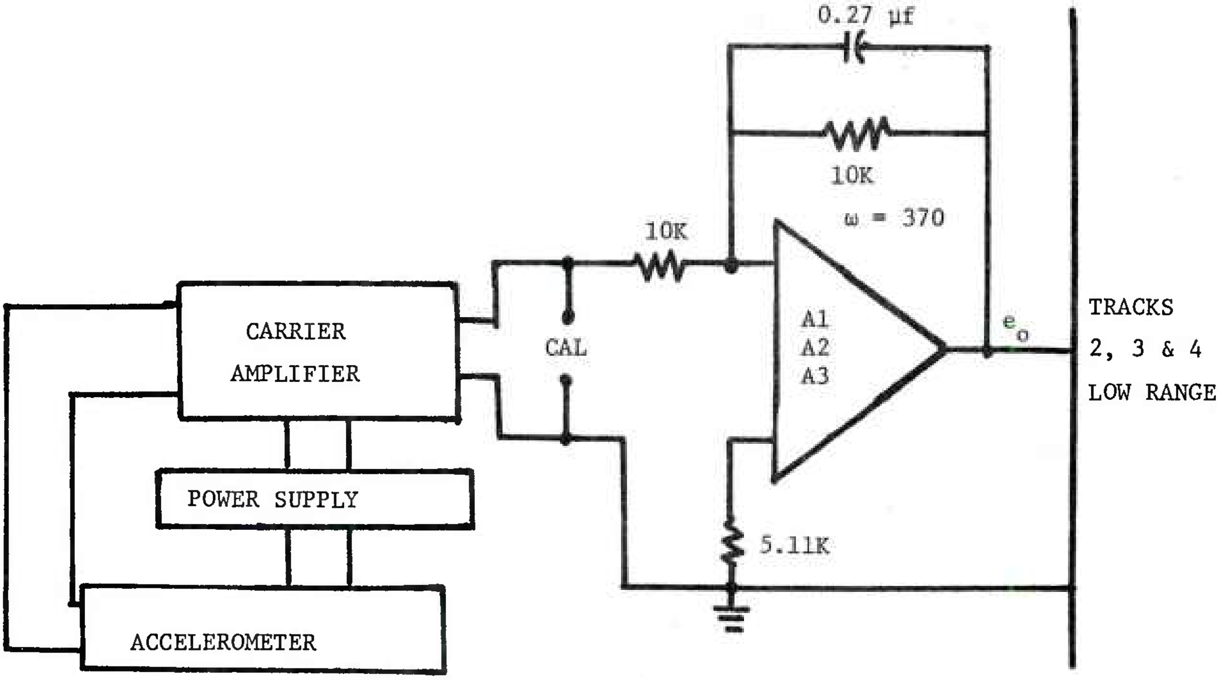
TRACK 4 TURRET ACCELERATION (VERTICAL)

The purpose of these tracks was to measure and record the linear accelerations of the turret along three orthogonal axes. This was achieved by mounting three strain gage accelerometers in the rear of the turret. The side-side and vertical accelerometers were mounted on the face of the vertical gyro mounting block while the fore-aft accelerometer was mounted on the back of the former turret-roll rate gyro mounting pad. Bubble levels were used to accurately align the three accelerometers.

The side-side and fore-aft accelerometers were initially scaled to measure ±1 g peak acceleration which results in ∓1 V_{DC} out of the carrier amplifiers as shown in the track schematic, Figure 23. These signals into unity gain, inverting amplifiers results in ±1 V_{DC} being recorded on tracks 2 and 3. The vertical accelerometer was initially scaled to measure ±1 g about the existing ±1 g field. This results in an expected swing of 0 to +2 V_{DC} being recorded on track 4. Each track was filtered at 59 Hz to attenuate higher frequency vibrations that might appear in the data.

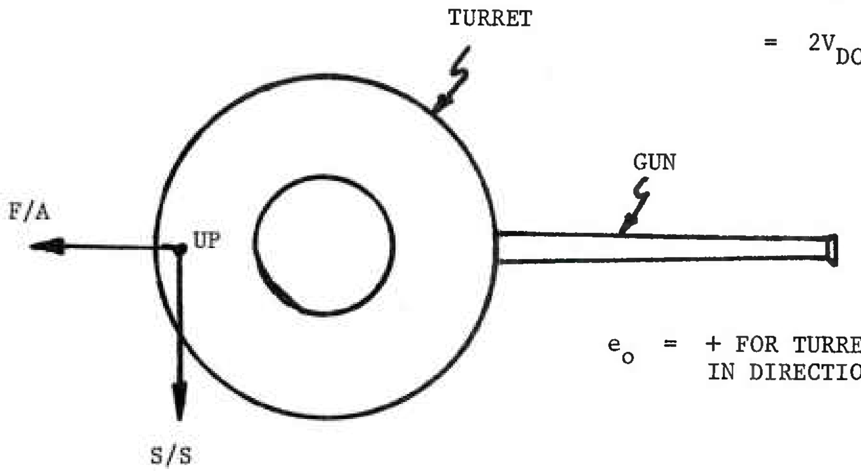
On 10 November 1972 a problem developed in the carrier amplifier power supply. The gage voltage to the accelerometers was fluctuating wildly between 0 and 5 volts. The problem was traced to a vacuum tube making intermittent contact in its socket. The solution was to use solder to increase the diameter of the tube's contact pins.

After the repair was made the three accelerometers should have been individually recalibrated with regard to acceleration level and output voltage. This was not done since it would involve dismounting the accelerometers from their carefully aligned positions. Since time was of the essence, the vehicle was driven onto a relatively level section of terrain which would put two accelerometers in a level position and one in a vertical position. The output of one of the level accelerometers was then used to provide a 0 g reference to all three tracks while the vertical



CAL = $1V_{DC}$ = 1g (S/S & F/A)

= $2V_{DC}$ = 2g (VERT)



e_o = + FOR TURRET ACCELERATION IN DIRECTION OF ARROWS

TURRET ACCELERATIONS

TRACK 2	SIDE - SIDE
TRACK 3	FORE - AFT
TRACK 4	VERTICAL

Figure 23 Track Schematic

accelerometer provided the +1 g reference.

The test equipment was calibrated at the conclusion of the standard tests with the following results.

	Carrier Amp. Output at:		
Accelerometer	+ 1 g	- 1 g	0 g
Side-Side	-1.033V	+0.947V	-0.027V
Fore-Aft	-0.895V	+1.015V	+0.052V
Vertical	-1.047V	+0.784V	-0.092V

This data is plotted in Figure 24 and displays good to excellent linearity characteristics. From this data and the fact that the calibration signals remained unchanged, the following accelerometer scaling can be inferred by using a two slope method for each track.

	Actual Accelerometer Scaling		
Cal Signal	Side-Side	Fore-Aft	Vertical
-1V = +40% dev.	+0.967 g	+1.11 g	
0V = 0% dev.	-.028 g	+.055 g	-.105 g
+1V = -40% dev.	-1.054 g	-.984 g	
-2V = +40% dev.			+2.00 g
+2V = -40% dev.			-2.39 g

TRACK 5 RIGHT TRACK MOTION

TRACK 7 LEFT TRACK MOTION

The purpose of this instrumentation was to record the vehicle's actual forward speed rather than rely on the vehicle's driver to maintain a nominal speed for a given test condition.

The method chosen is shown in Figure 25 whereby magnetic pickups were mounted on each side of the vehicle near the track's drive sprockets. Each magnetic pickup was mounted in an aluminum bracket and sensed the passage of the five steel spurs bolted to the drive sprocket. The passage of a spur by the pole piece of the magnetic pickup would produce a dynamic discontinuity of magnetic material in the field of the pickup which produces a voltage pulse at the sensor output.

Measurement of the vehicle's track indicated that for one revolution

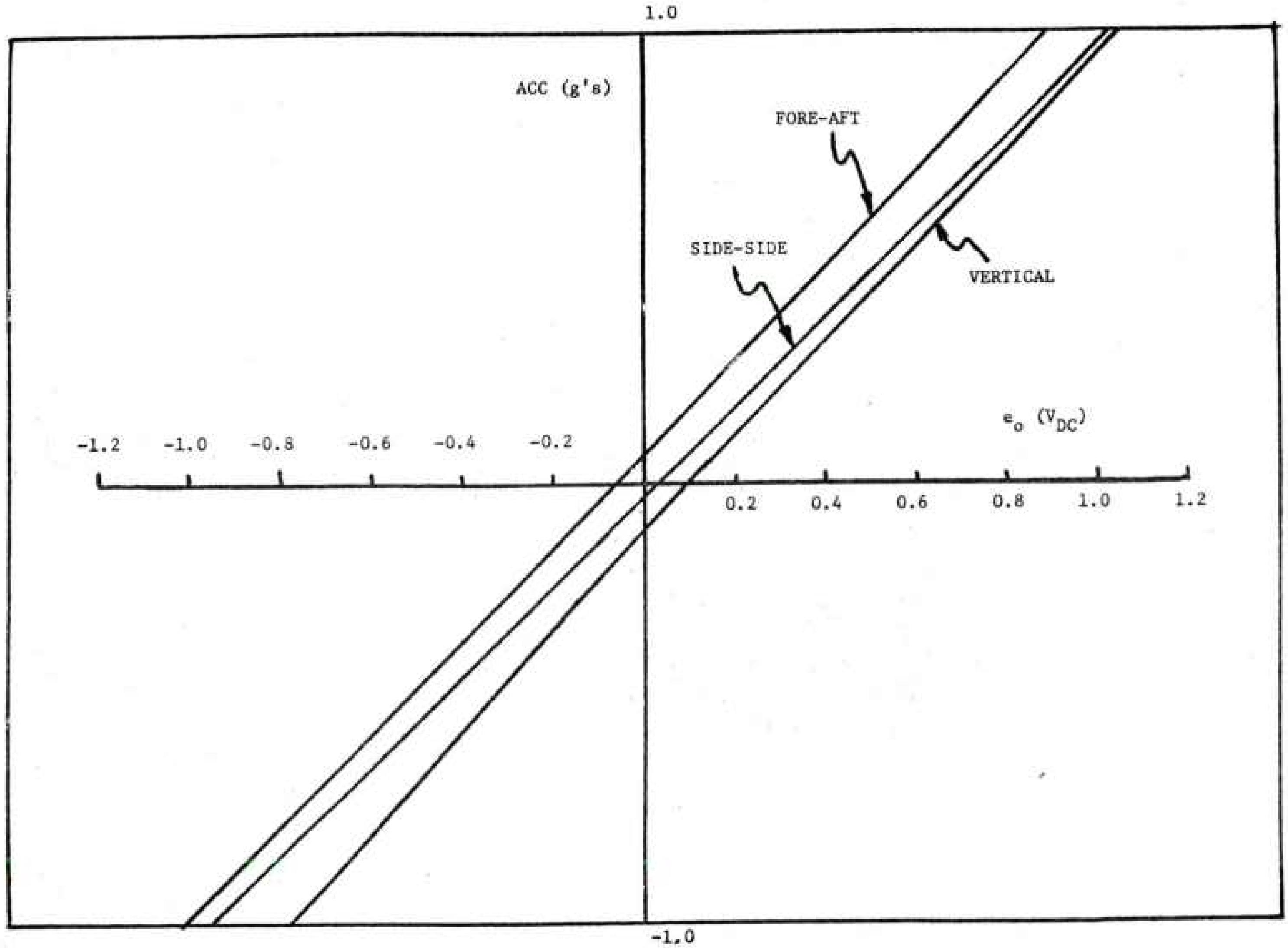


Figure 24 Final Accelerometer Scaling

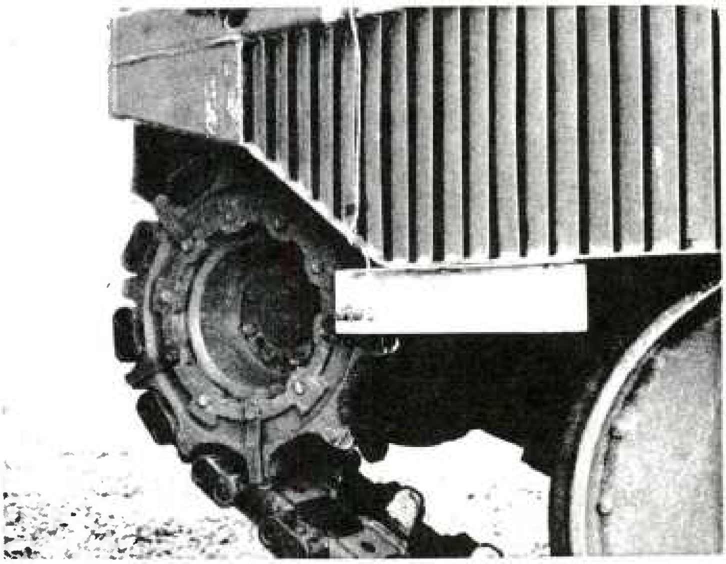


Figure 25 Magnetic Pickup Sensing Left Sprocket Rotation

of the drive sprocket, the track would advance 61¼". Thus each pulsed output of the pickup indicates that the vehicle has moved by 12¼". The time between pulses can then be used to compute the vehicle's velocity. When the vehicle is turning, the turning rate can be evaluated by the different pulse frequencies at the right and left tracks. This information is also present in a more direct form in the hull yaw rate signal of Track 17.

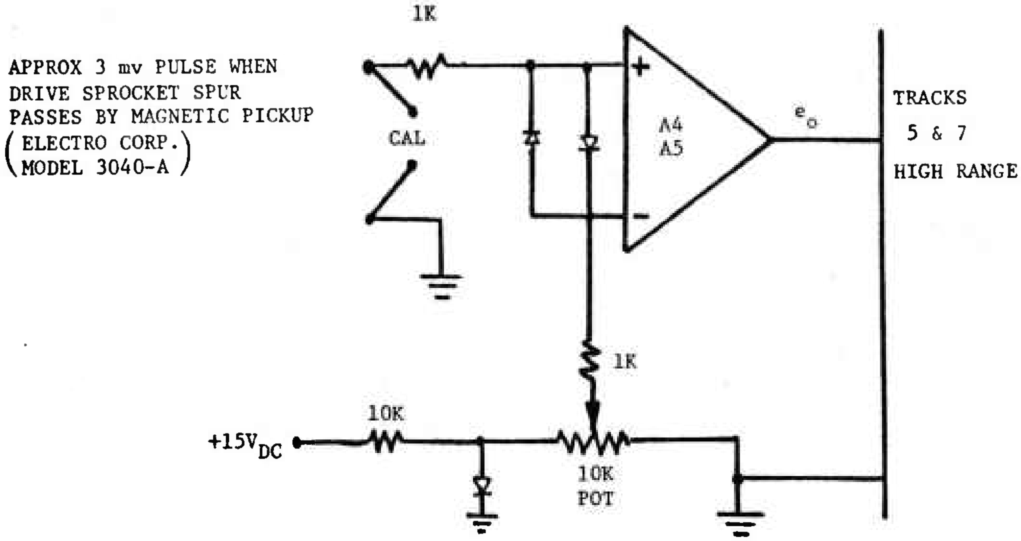
The electronics associated with the pickups are shown in the track schematic, Figure 26. With zero output from the pickup the output of the instrumentation amplifier should be saturated at -12 to -14 V_{DC}. This condition is caused by the positive bias voltage appearing at the inverting input of the amplifier. When a drive sprocket spur passes by the pickup, the pickup's small positive output is large enough to overcome the bias signal and drive the amplifier output to a saturated positive voltage. The amplifier output then drops to a negative saturated output after the passage of the spur. The calibration signal used for these tracks bears no relation to the gradient of sensor output. It was merely used to insure amplifier saturation during the recorder calibration.

Early in the test period a problem developed in the right track motion signal. The tape playback indicated that the magnetic pickup was not only sensing the passage of the five steel spurs, but also the passage of the sprocket teeth between the spurs. The problem was traced to the range switch on the Track 5 record board being in the LOW rather than HIGH range position. Inspection of data taken near the conclusion of the standard tests indicates that this track was then operating properly. Previous data can be corrected by comparing indicated speed against nominal speed on a straight course run to see if a 2:1 speed divisor is needed.

TRACK 6 TAPE SYNCHRONOUS CONTROL

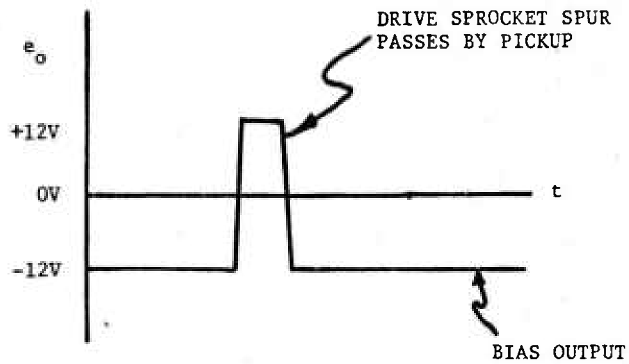
The accuracy achieved in reproducing data stored on magnetic tape is largely dependent upon the relationship of reproduced speed to recorded speed. In FM recording, the major effect of a tape speed error is to affect the amplitude of the reproduced data.

During the record mode the tape speed is controlled by using an



CAL = 0.8 V_{DC}

e_o = 12 - 14 V_{DC}



TRACK 5 RIGHT TRACK MOTION

TRACK 7 LEFT TRACK MOTION

Figure 26

internally generated crystal oscillator signal as the command input to the capstan's velocity feedback servo. Sangamo's equipment specifications indicate that a negligible tape velocity error results from their servo design. During the recording process, the crystal oscillator signal was recorded on Track 6.

When the tape is reproduced, this signal is recovered from the tape and is compared to the crystal oscillator reference frequency. If a different tape recorder is being used for playback, the capstan drive will change speed so that the recorded signal frequency conforms to the new reference frequency which controls the reproduced electronics and the amplitude of the reproduced data.

The recorded speed reference signal is also of value if the data is reproduced on the same tape recorded used for recording. Changes in tape dimension due to temperature and humidity effects and changes in crystal oscillator reference frequency due to the shock and vibration environment are automatically compensated when the data is reproduced.

TRACK 7 LEFT TRACK MOTION

Track 7 is a duplicate of Track 5 and is described under that title. (Figure 26).

TRACK 8 TRAVERSE MOTOR CURRENT

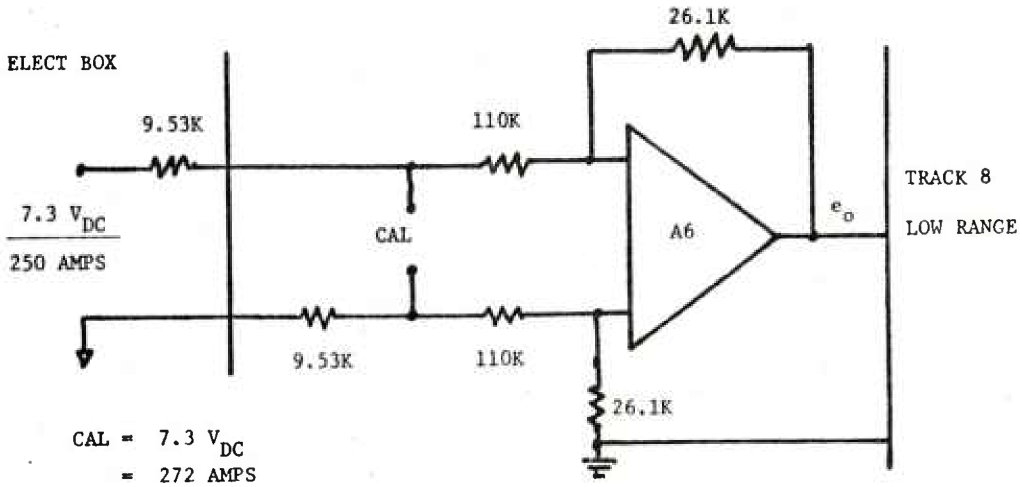
TRACK 9 ELEVATION MOTOR CURRENT

The traverse and elevation motor currents were recorded for purposes of calculating motor torque (referred to load speed) plus peak and RMS power consumption as the vehicle was driven over several types of terrain. A model of the torque output of these non-linear split-series motors has been published in the Cost/Performance Study report. Power calculations can be made by assuming a 24 V_{DC} battery power source.

As shown in the track schematic, Figures 27 & 28, the current signals were fed into double-ended amplifiers to eliminate ground loop problems.

TRACK 10 GUN ELEVATION POSITION

As shown in the track schematic, Figure 29, a potentiometer was used to record the elevation position of the gun relative to the turret. The pot had 3600° of mechanical and electrical rotation and was driven by the 40.3 speed shaft of the elevation gear box.

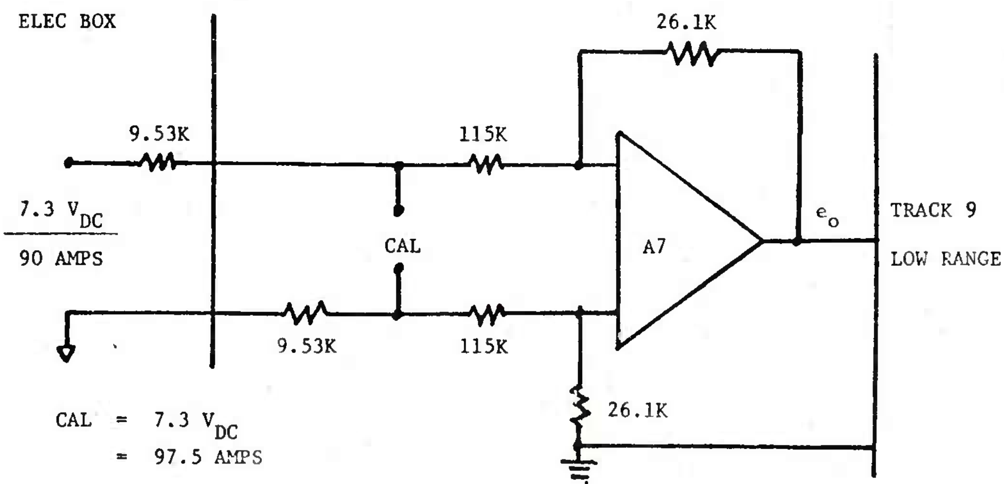


CAL = 7.3 V_{DC}
= 272 AMPS

e_o = + FOR TURRET ACCELERATING CW AS VIEWED FROM ABOVE

TRACK 8 TRAVERSE MOTOR CURRENT

Figure 27

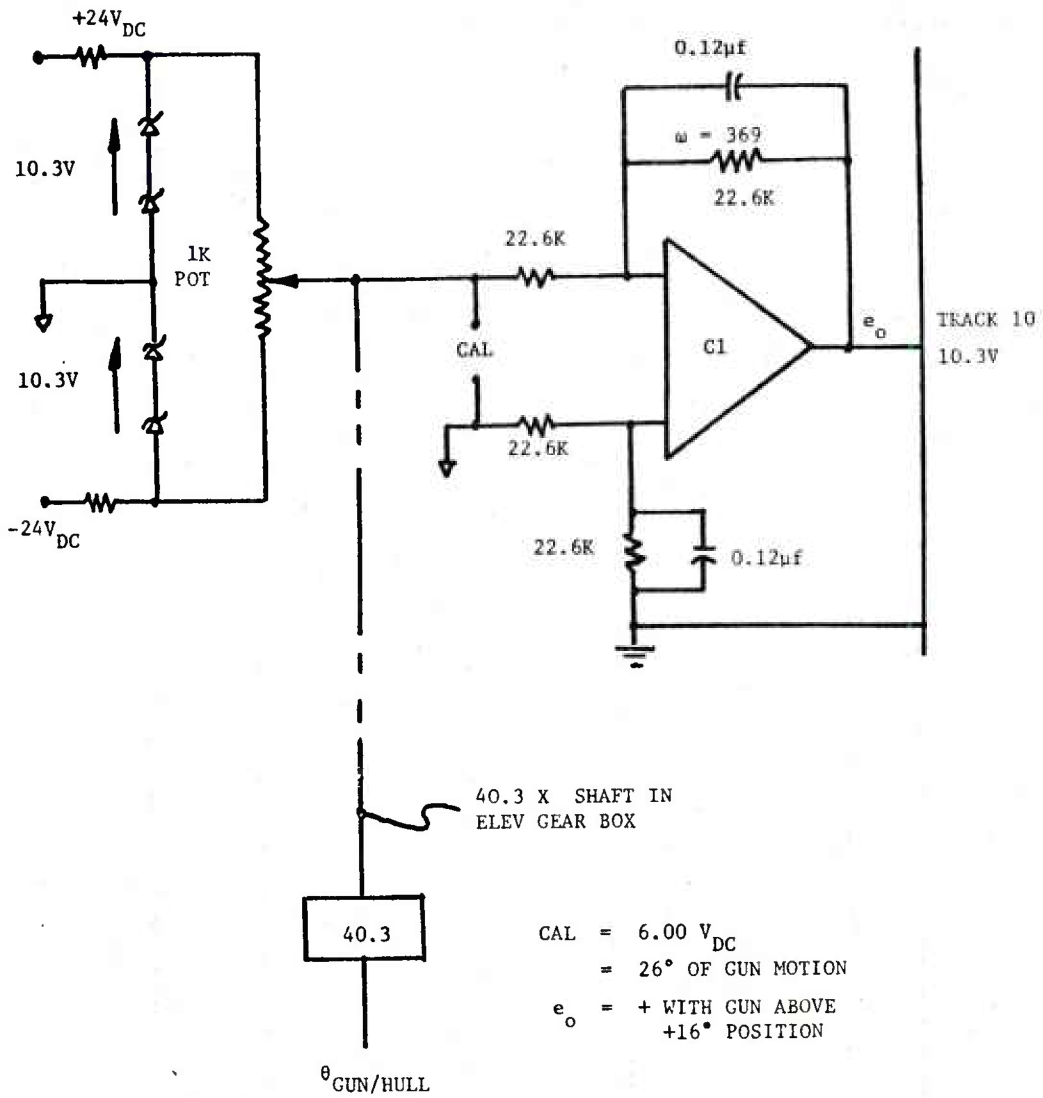


CAL = 7.3 V_{DC}
= 97.5 AMPS

e_o = + FOR GUN ACCELERATING UPWARDS

TRACK 9 ELEVATION MOTOR CURRENT

Figure 28



TRACK 10 GUN ELEVATION POSITION

Figure 29

The mechanical limits of gun travel are +60% of elevation and -10° of depression. The pot shaft was rotated at its coupling to provide a 0V output at +16° of gun elevation. In this manner the ±44.6° of pot rotation (referred to load speed) was used to bring the 0V output of the pot to its lowest possible mechanical position.

The 6 V_{DC} cal signal is equivalent to ±26° of gun travel about the +16° position. With the exception of a high speed bump course run, the gun angle should always be less than +16° which results in a negative signal into the track input. The instrumentation amplifier was filtered at 59 Hz to reduce noise from the wirewound pot.

TRACK 11 GUN TRAVERSE POSITION

This track recorded the traverse position of the gun relative to the hull. As shown in the track schematic, Figure 30, a potentiometer was used to measure turret rotation relative to the hull. The pot had continuous mechanical rotation and 350° of electrical rotation. The shaft of the pot was driven by a 25:1 speed reducer which was coupled to the 25.41 speed shaft of the traverse gear box. The inexact matching of gear ratios causes the pot to rotate 365.9° while the turret rotates 360°.

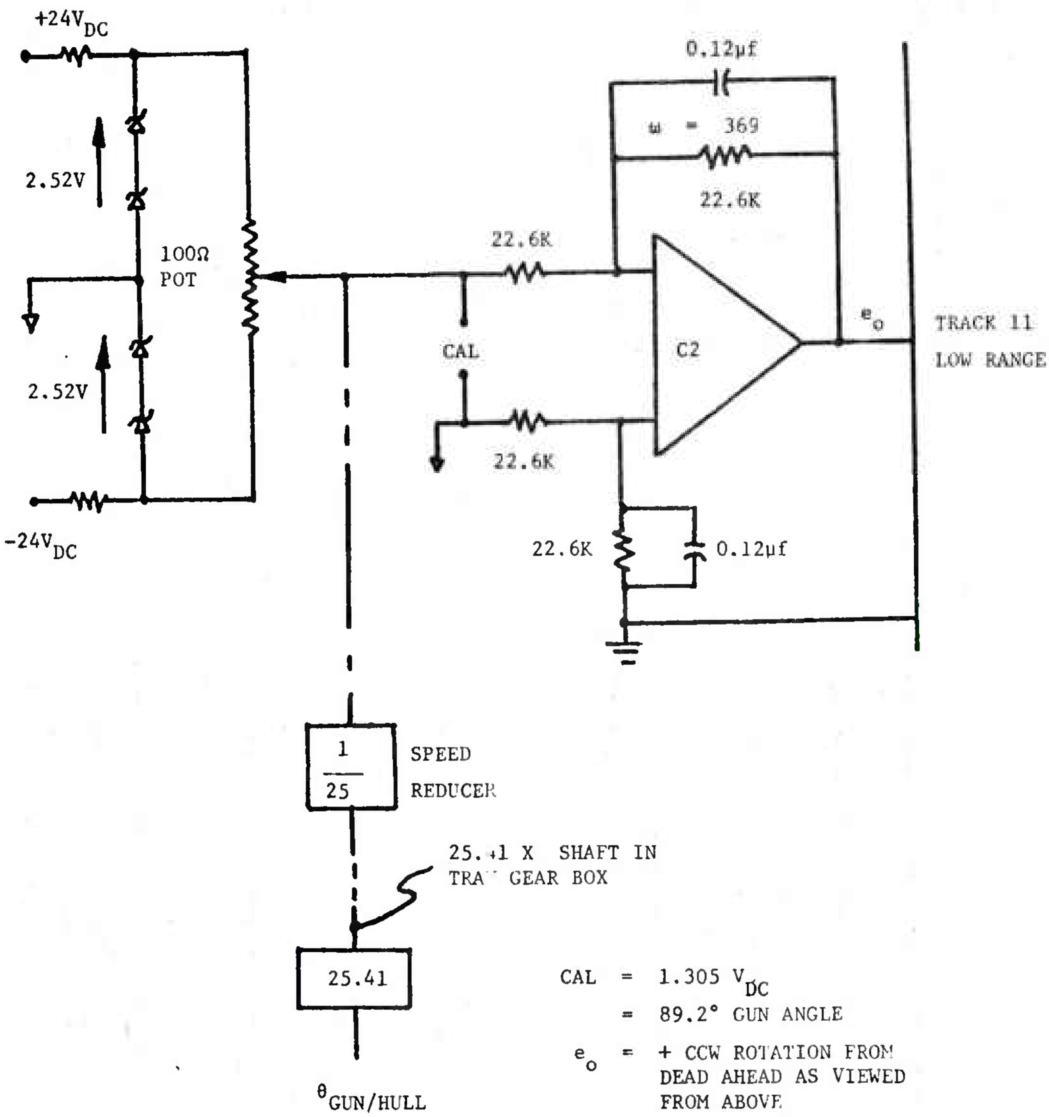
This mismatching of gear ratios introduced an extra detail to the test. The gun was rotated to a dead ahead position and the turret stow pin was then engaged. The minimum pot output in this position was +35.9 mv. An additional 360° turn of the turret in either direction would result in a ±81.5 mv change in the pot output. The 35.9 mv position was chosen as the 0° position of the gun. Care was taken to unwind the turret to this position at the start of each run when time and conditions would permit.

The 1.305 V_{DC} cal signal is equivalent to 90.6° of pot rotation which results in 89.2° of turret rotation. The amplifier was filtered at 59 Hz to reduce noise from the wirewound pot.

TRACK 12 GUN ELEVATION VELOCITY

TRACK 13 GUN TRAVERSE VELOCITY

These two tracks used the elevation and traverse motor speed tachometers to record the two-axis velocities of the gun relative to the vehicle's turret and hull. The tach gradients, shown in the schematics,



TRACK II GUN TRAVERSE POSITION

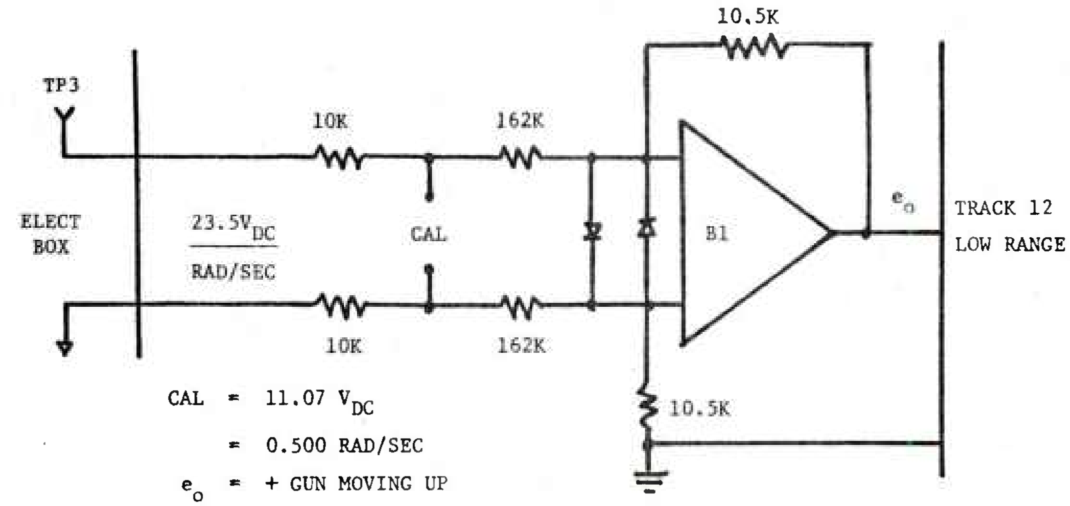
Figure 30

Figures 31 & 32 have been referred to load speed. The 10K resistors on the amplifier's input were installed in the turret wiring to prevent any accidental shorting of the tach output by breakage of the external instrumentation cables. The presence of these resistors has been factored into the calibration voltage levels.

The calibration signals for these tracks might be considered non-standard since the tracks were not calibrated to yield a 40% frequency deviation at the tape recorder. Since the calibration box power supply was only 15 V_{DC}, the full scale tach outputs could not be simulated by the calibration signals. The Track 12 calibration signal was designed to give the same instrumentation amplifier output as the elevation tach would when its load speed velocity was 0.500 rad/sec. Under this condition the Track 12 FM record board was adjusted for a 20% frequency deviation. During the tests, the elevation tach output could double at 1 rad/sec and yield the usual 40% frequency deviation at the maximum input level. The Track 13 calibration signal follows the same scheme and was designed to produce a 13 $^1/_3$% frequency deviation in the cal signal level.

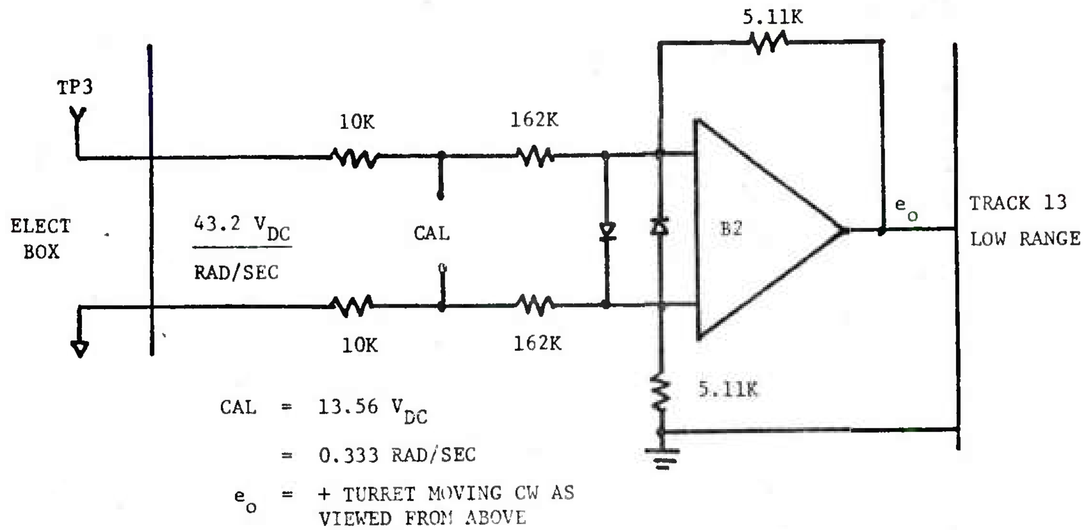
On 29 November 1972 the gunners reported that the elevation power drive became unstable only during gun firing. On 30 November the problem was traced to a broken coupling that connects the elevation tach to the servo motor. A burr at the broken section of the coupling had kept the coupling engaged under all conditions except gun firing. A spare coupling was used to repair the problem.

At the conclusion of the standard tests, the last run was played back onto the visicorder to insure proper operation of all tracks. At the time the traverse tach signal showed a straight line on the paper when there should have been some movement. The turret was then rotated with all wiring undisturbed. The tach signal was successfully recorded and reproduced. The conclusion is that an intermittent connection developed sometime during the test period. This signal can still be retrieved, with reduced accuracy, by using the signals from the hull yaw velocity (Track 17), gun traverse velocity (Track 15), gun elevation position relative to the hull (Track 10) and taking the difference of relative rates with the gun traverse velocity referred to a train rate by the cosine of the



TRACK 12 GUN ELEVATION VELOCITY

Figure 31



TRACK 13 GUN TRAVERSE VELOCITY

Figure 32

relative gun elevation angle.

TRACK 14 GUN ELEVATION VELOCITY

TRACK 15 GUN TRAVERSE VELOCITY

An important data item is the ability of the stabilized power drives to isolate the gun from disturbances generated by the motion of the hull. These disturbances occur predominantly at the 1 H_Z natural frequency of the hull and its suspension. The gun's elevation and traverse velocity errors were recorded from the gun gyro outputs. Numerical integration can then be applied to the digitized playback data to yield the position errors.

As shown in the track schematics, Figure 33 & 34, the tracks were initially scaled to record about 25 mrad/sec of velocity error from the gun gyros. On 8 November 1972 it was reported that 35 to 40 Hz vibrations were saturating the FM record inputs on both tracks. This was probably caused by the vehicle's engine vibration or track cogging action being sensed by the gun gyros.

The tracks were then rescaled to about 60 mrad/sec full scale. It was intended that 15 to 20 H_Z low pass filters would also be added to attenuate the high frequency vibration and preserve the information occurring at 1 Hz. Subsequent reflection in a cooler atmosphere reveals that when the filters were added, the break frequencies were actually 1.74 Hz (elevation) and 1.52 Hz (traverse). This error can be corrected during the digital integration by adding the appropriate lead break as a series compensation to the integrator. In this manner the higher frequency information will be amplified back to its real world value. The timing of all track changes was noted on the tape for future reference.

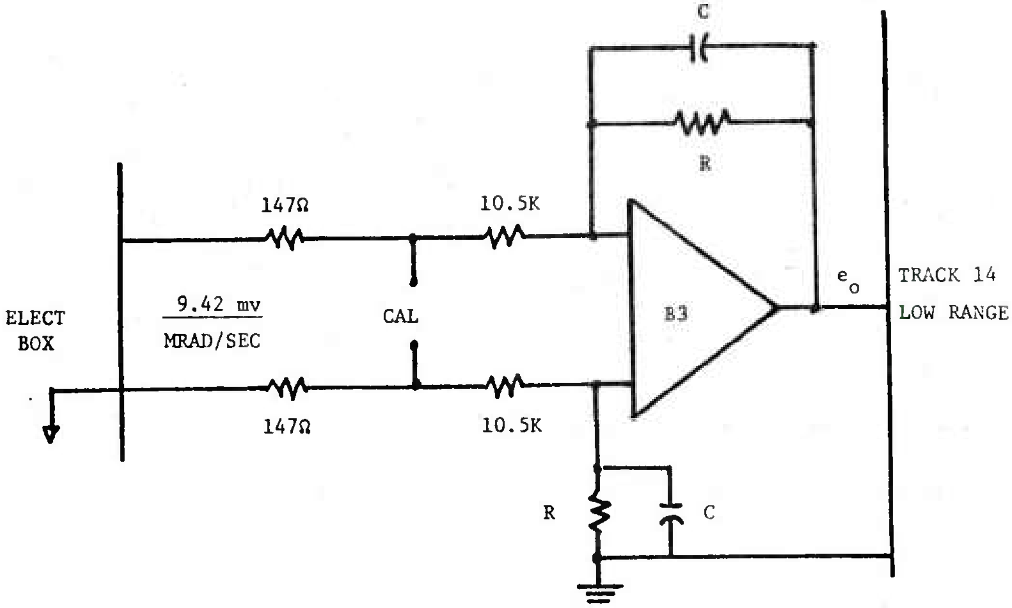
TRACK 16 TURRET PITCH VELOCITY

TRACK 17 HULL YAW VELOCITY

The angular velocities of the turret's pitching motion and the hull's turning rate were recorded by using the outputs of the turret pitch and hull yaw rate gyros. As shown in the track schematic, Figures 35 & 36, the instrumentation was straight forward with no known problems encountered.

TRACK 18 TURRET PITCH ANGLE

TRACK 19 TURRET ROLL ANGLE

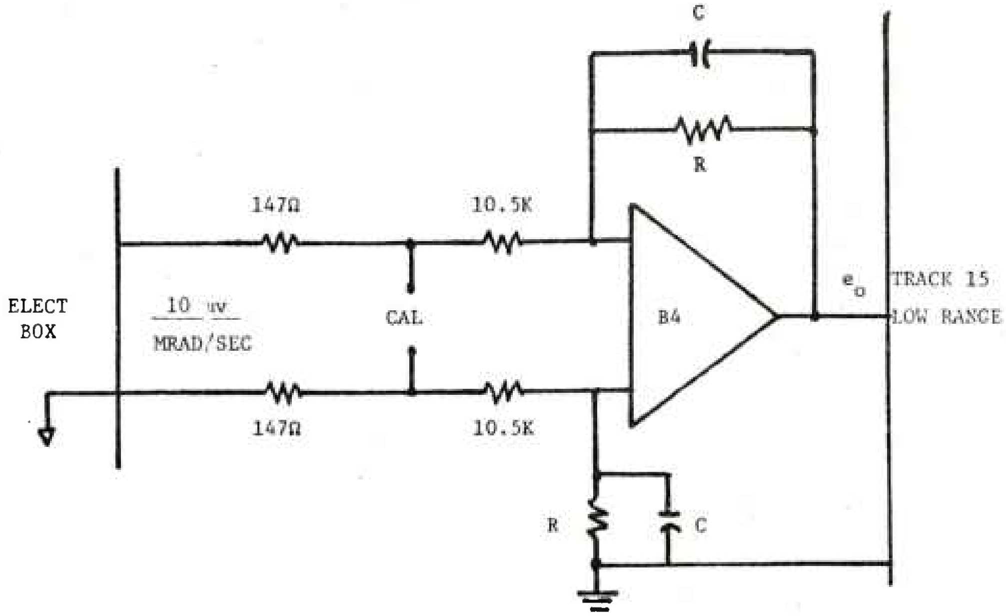


e_o = + GUN MOVING DOWN

	R	C	CALIBRATION
INITIAL SCALING	56.2K	NOT USED	0.246 V_{DC} = 26.5 MRAD/SEC
FINAL SCALING	36.5K	2.5µf	0.592 V_{DC} = 63.7 MRAD/SEC

TRACK 14 GUN ELEVATION VELOCITY (RELATIVE TO SPACE)

Figure 33

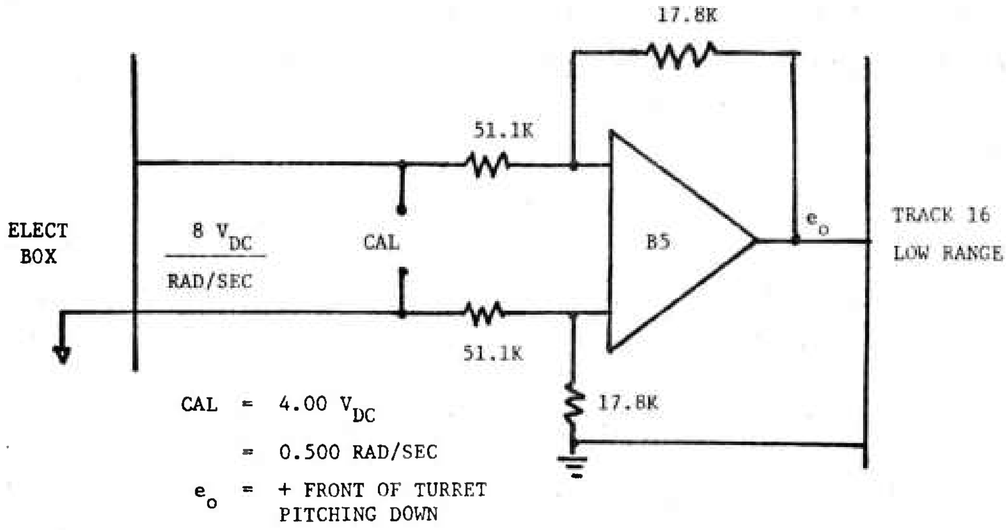


e_o = + GUN MOVING CCW AS VIEWED FROM ABOVE

	R	C	CALIBRATION
INITIAL SCALING	56.2K	NOT USED	0.246 V_{DC} = 24.9 MRAD/SEC
FINAL SCALING	34.8K	3.0μf	0.592 V_{DC} = 60.0 MRAD/SEC

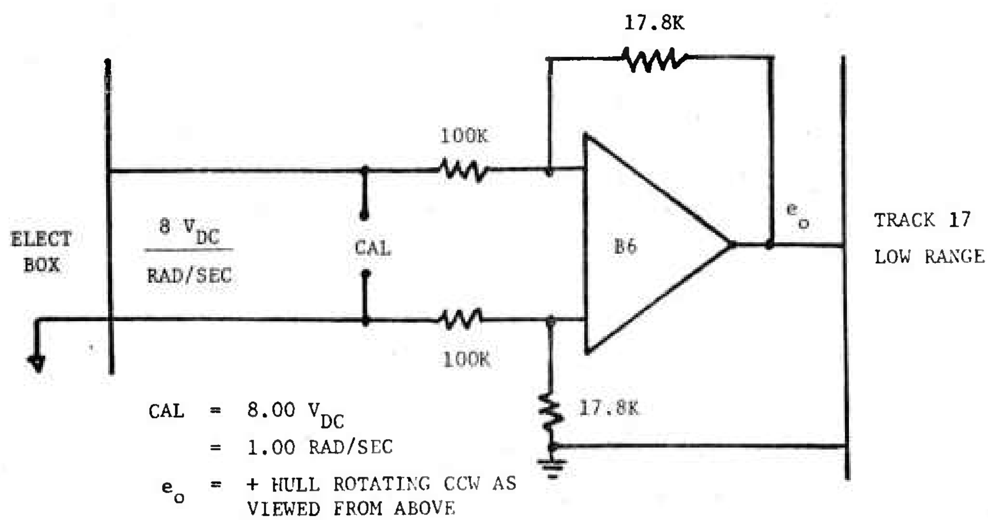
TRACK 15 GUN TRAVERSE VELOCITY (RELATIVE TO SPACE)

Figure 34



TRACK 16 TURRET PITCH VELOCITY

Figure 35



TRACK 17 HULL YAW VELOCITY

Figure 36

This instrumentation recorded the inertial roll and pitch angles of the turret by using a vertical gyro. The vertical gyro used was the Lear Siegler model 9000C. The 115 V_{RMS}, 400 Hz gyro power was supplied from a solid state inverter connected to the vehicle batteries.

Figure 37 details the electronics used to demodulate, amplify and filter the synchro outputs from the two axes of the vertical gyro. The synchro outputs are fed into amplifiers D3 and D4 where they are phase-sensitive demodulated with the demod reference coming from amplifier D1. The D5 and D6 amplifiers then amplify the signals and use a 45.7 Hz filter to attenuate the 800 Hz ripple that appears in the demod output. The track calibration signal appearing at the output of amplifier D2, is derived directly from the power supply voltage. This scheme ties the cal signal voltage to the synchro reference voltage.

Switches were provided on the box containing the vertical gyro electronics to produce the positive, negative and 0V cal signals.

An overview of the instrumentation is provided by the track schematic, Figure 38. The synchro's nominal output of 11.8 V_{RMS} at 90° of axis rotation was found to be actually 12 V_{RMS} by a calibration performed before testing started. The results are shown in Figures 39 and 40. The tracks were scaled with a calibration signal that represented 20° of roll or pitch angle.

TRACK 20 GUNNER'S HS INPUT (ELEVATION)

TRACK 21 GUNNER'S HS INPUT (TRAVERSE)

The gunner's two-axis handstation is shown in Figure 41. This handstation uses pots to covert the handgrip rotation angles into electrical signals that command the gun's space velocity in two axes. The pots are tapered to provide a low signal gradient condition for fine tracking with a subsequently increasing gradient to reach full slew velocity. As such, a non-linear relationship exists between pot output and physical rotation of the handstation. The objective of obtaining the handstation data was to record the actual target corrections made by the gunner rather than becoming involved in the human factors area of gunner's wrist motion required to produce the corrections.

As shown in the track schematics, Figures 42 and 43, the pot outputs

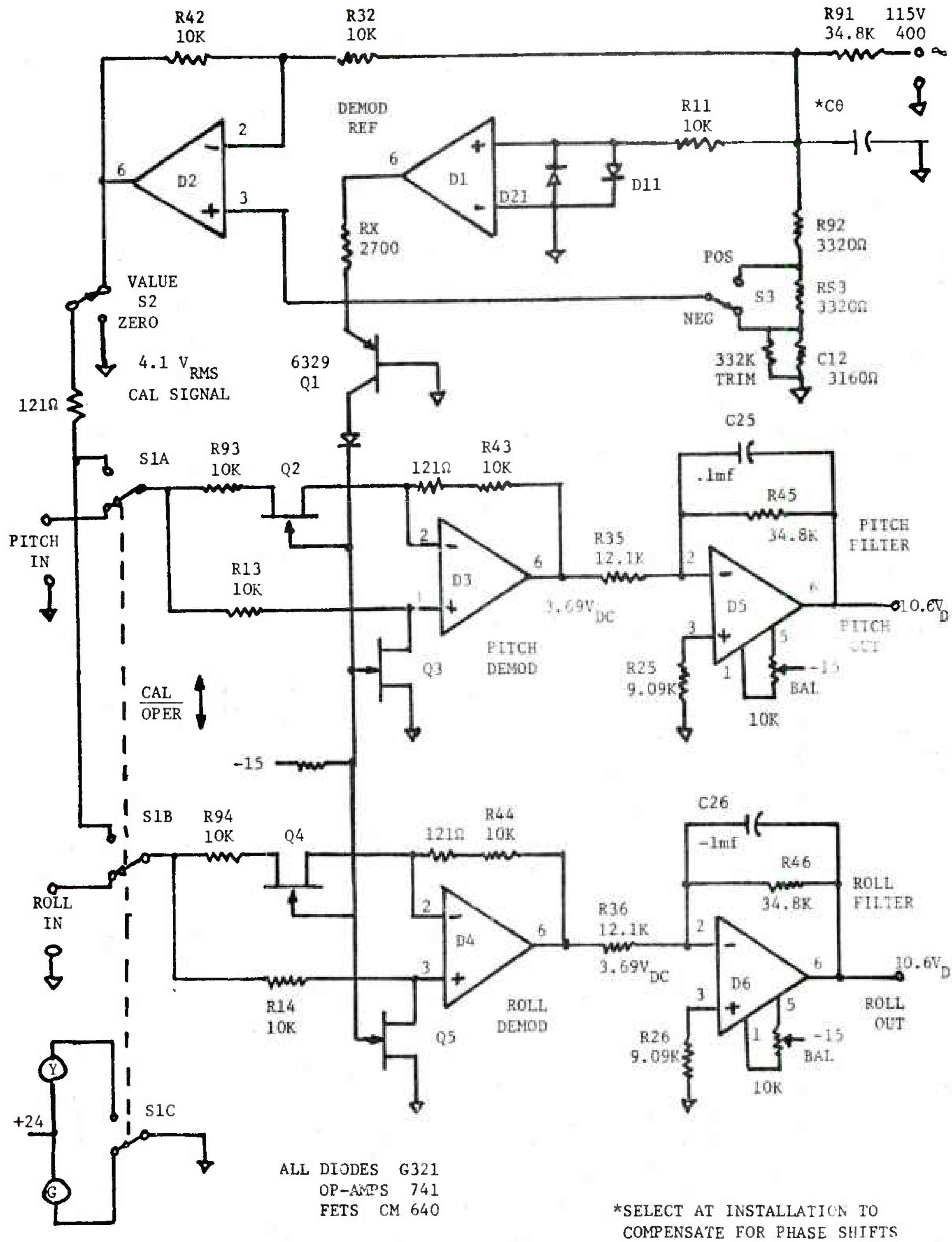
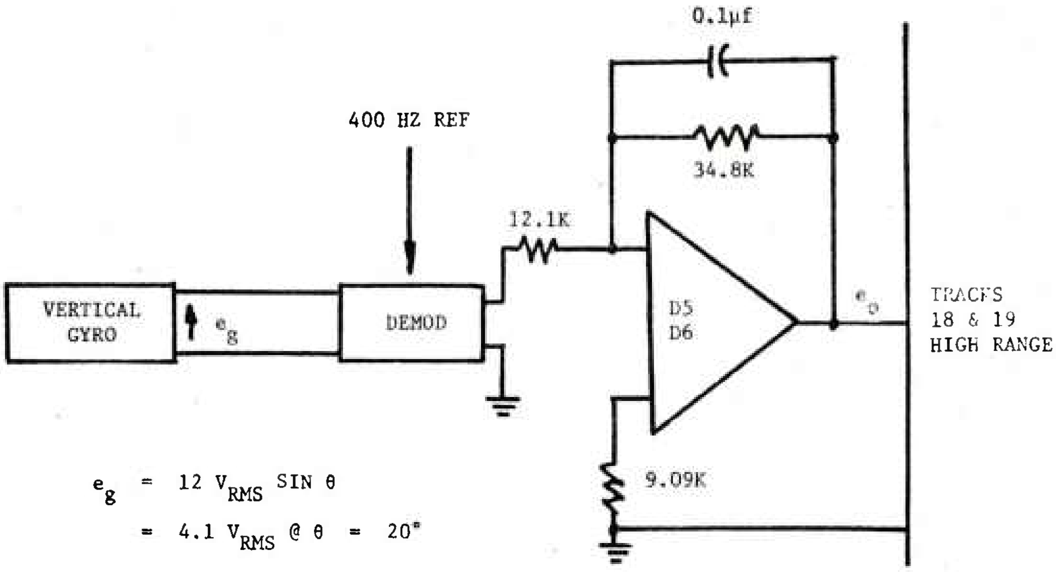


Figure 37 Vertical Gyro Electronics



e_g = 12 V_{RMS} SIN θ

= 4.1 V_{RMS} @ θ = 20°

TURRET PITCH

e_o = + FRONT OF TURRET PITCHED DOWN

TURRET ROLL

e_o = + TURRET ROTATED CW AS VIEWED FROM THE REAR

TRACK 18	TURRET PITCH ANGLE
TRACK 19	TURRET ROLL ANGLE

Figure 38

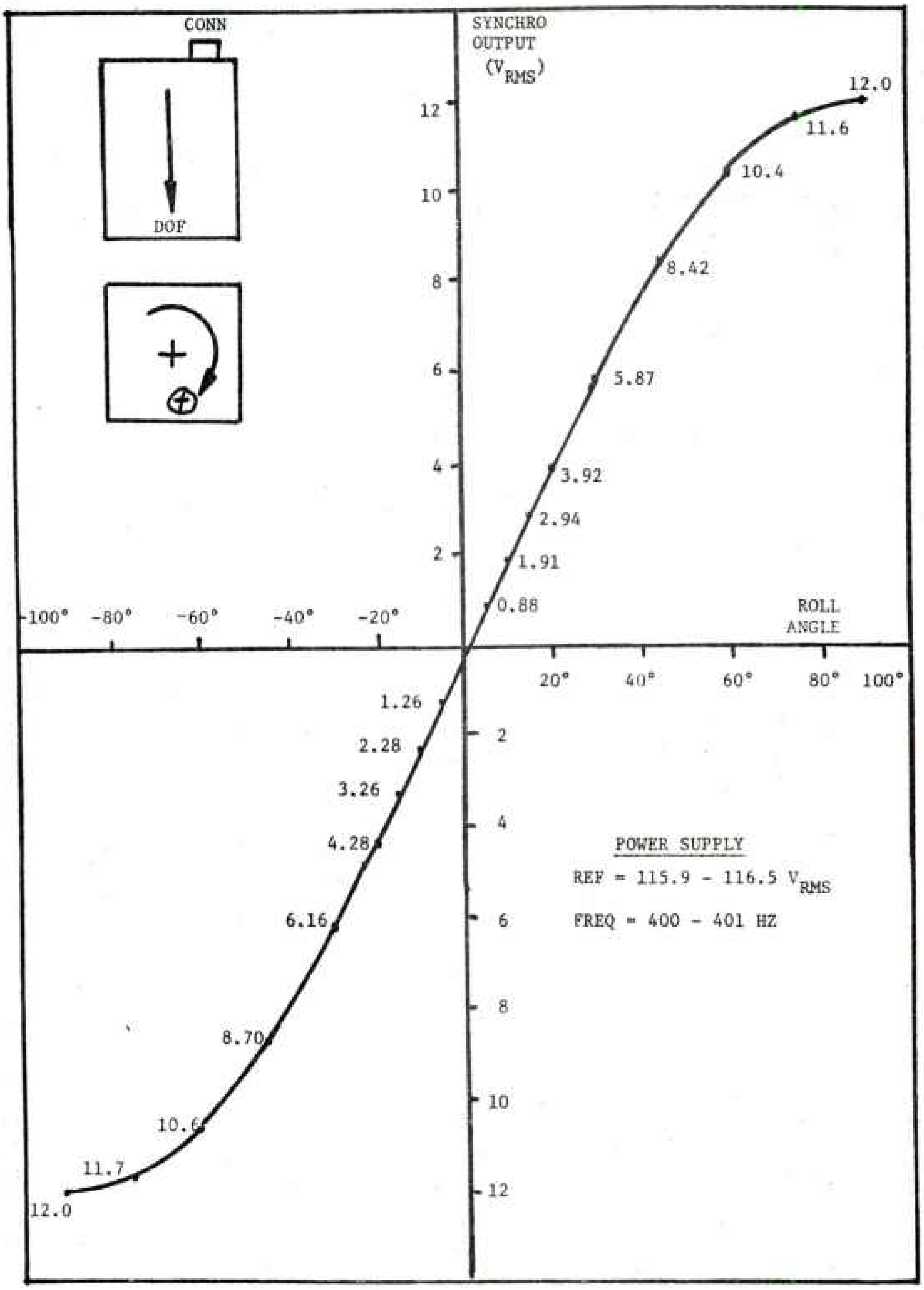


Figure 39 Vertical Gyro Calibration (Gyro Roll Axis) for Track 18

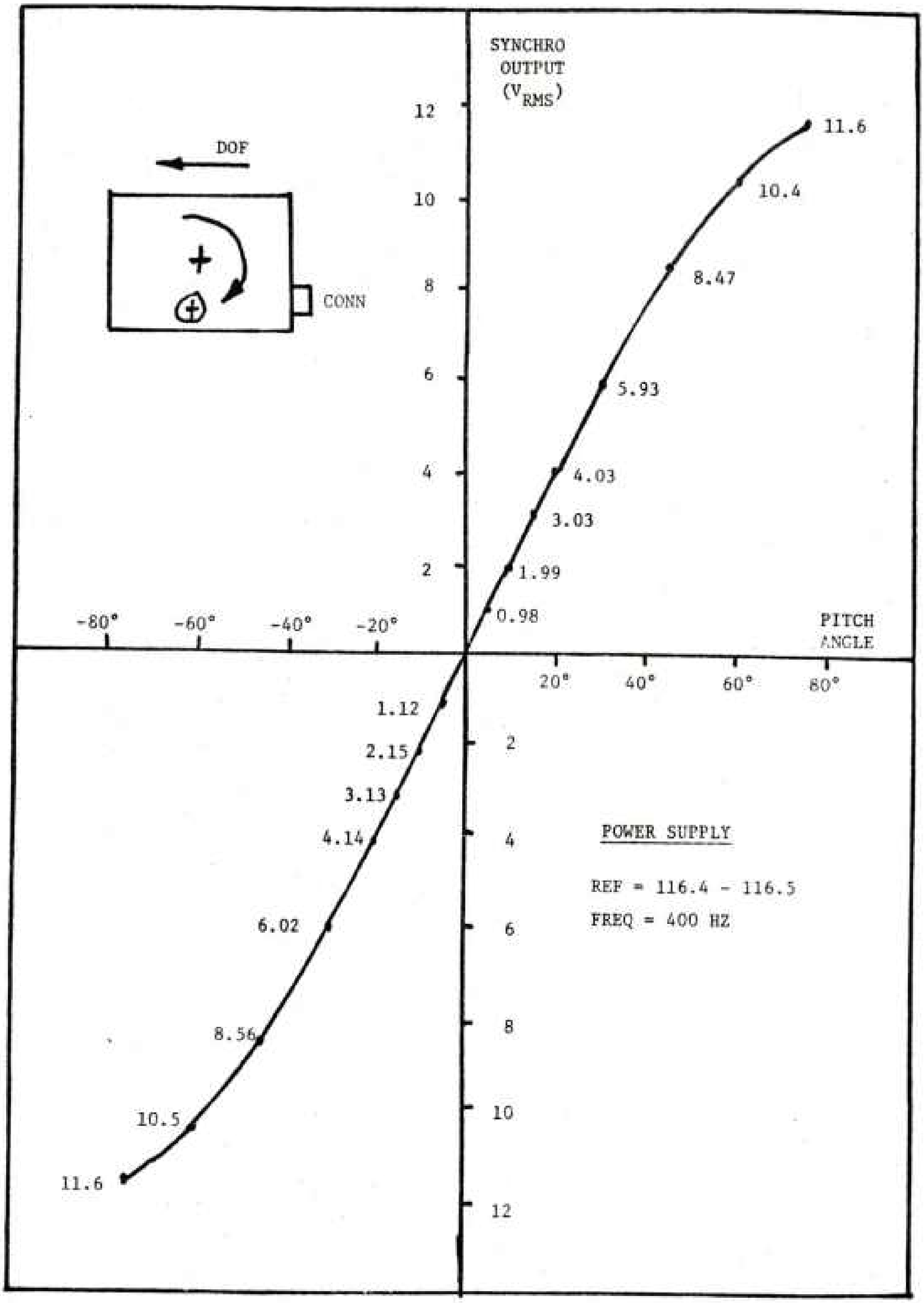


Figure 40 Vertical Gyro Calibration (Gyro Pitch Axis) for Track 19

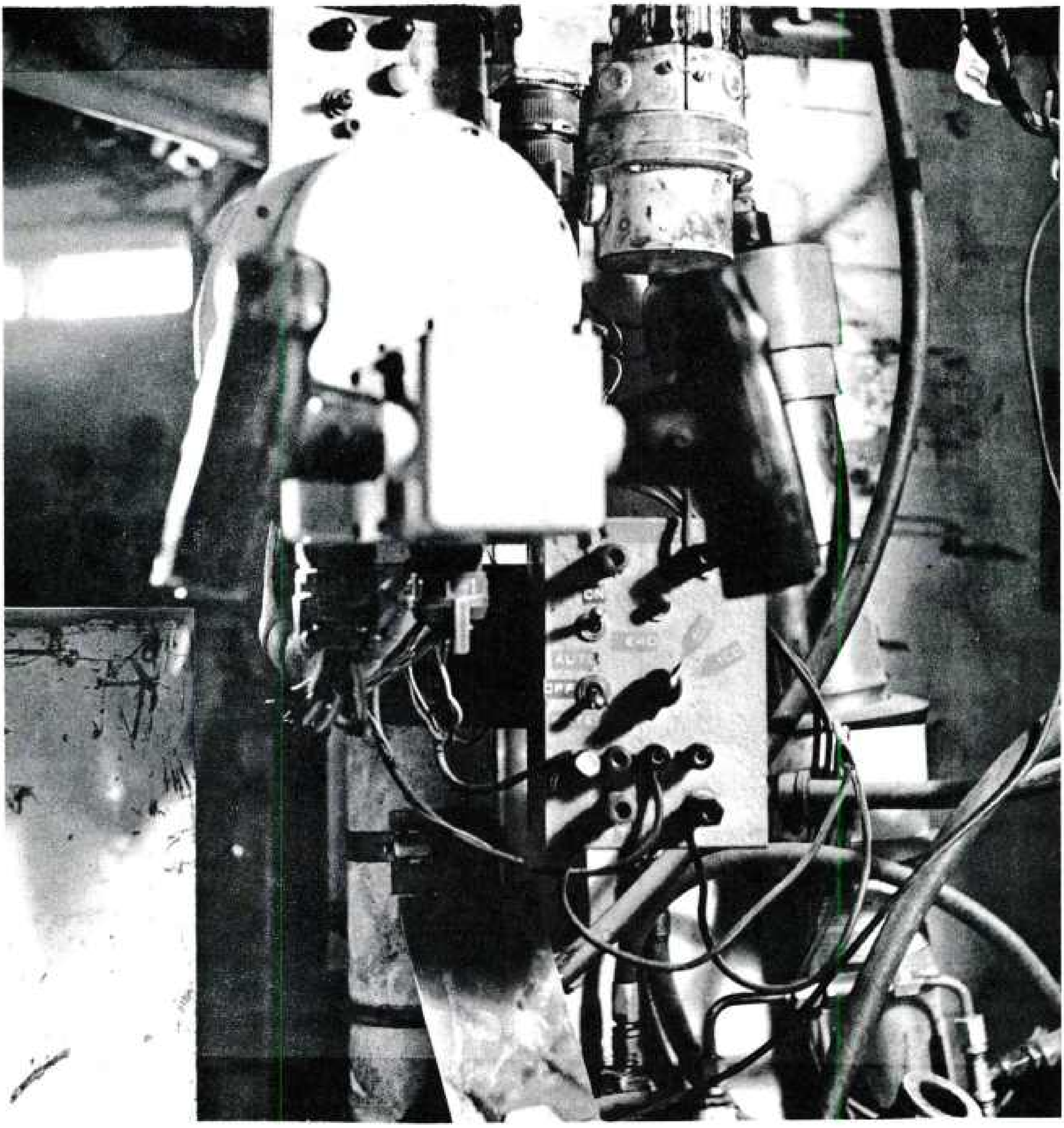
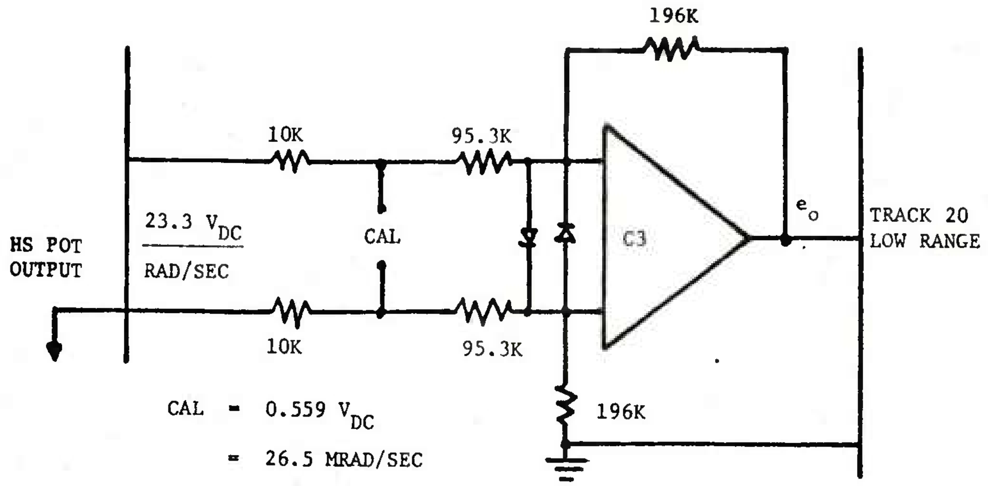


Figure 41   Gunner's Two-Axis Handstation



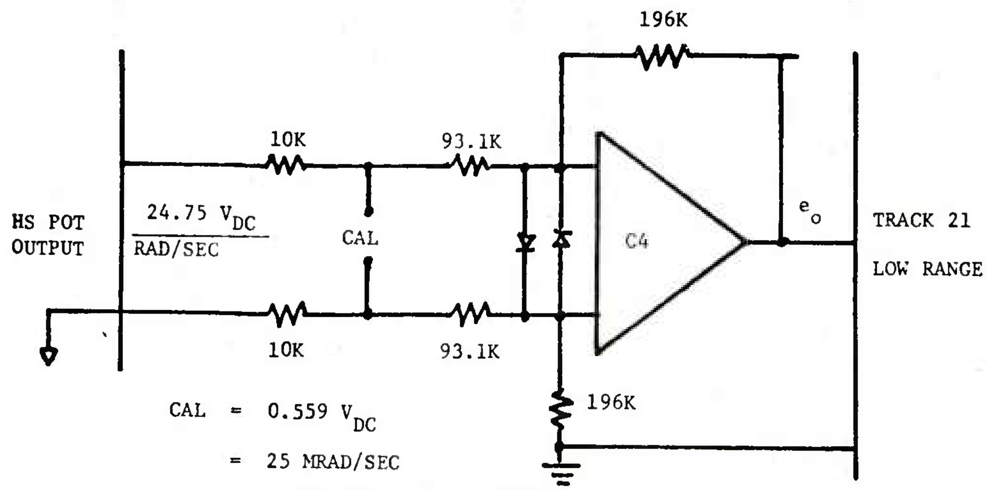
CAL = 0.559 V_{DC}

= 26.5 MRAD/SEC

e_o = + GUN UP

TRACK 20 GUNNER'S HS INPUT (ELEV)

Figure 42



CAL = 0.559 V_{DC}

= 25 MRAD/SEC

e_o = + GUN CW AS VIEWED FROM ABOVE

TRACK 21 GUNNER'S HS INPUT (TRAV)

Figure 43

were recorded which are linear with respect to commanded steady state velocity. The time constant involved in reaching steady state can be approximated by a double lag filter at 20 rad/sec.

On 20 November 1972 the gunners reported that, occasionally, an elevation handstation input would not cause any gun motion. Their comments were phrased in terms of a sticky elevation motor or a dead spot in the elevation handstation. At each occasion, they were able to temporarily correct the problem by using the elevation handcrank to manually exercise the gun. On 1 December 1972 the problem was traced to the elevation handcrank microswitch being out of adjustment. This switch is used to de-energize the elevation power drive whenever handcrank is engaged for manual operation of the drive.

TRACK 22 ROADWHEEL VERTICAL MOTION (RIGHT)

TRACK 23 ROADWHEEL VERTICAL MOTION (LEFT)

This instrumentation was designed to measure the bouncing motion of the hull when the vehicle was driven over a bump course type of terrain. The relative motion between the hull and the middle roadwheel was measured since this is essentially the motion of the vehicle's center of gravity. It should be noted that after the vehicle has gone over a bump and returned to flat ground, the bouncing motion of the hull relative to a flat track should occur at approximately a 1 Hz rate. Relative motions that do not occur at a 1 Hz rate may simply imply that a track has passed over an object and moved upward toward the hull without exciting the natural frequency of the hull and its suspension.

As shown in Figure 44 the measurement was made by mounting a pot on the road arm of each middle roadwheel. By means of an adapter, the body of the pot was clamped to the road arm's pivot point where it enters the bottom of the hull. The shaft of the pot was fixed to the hull by a pot shaft clamping bar that bolted to the tower structure on the hull. The net result is that the angular rotation of the road arm would be measured.

The vehicle was then driven onto a level concrete pad so that the hull could assume its normal rear position with respect to the roadwheels. In this position the center of the roadwheel was 3 3/8" below the pivot point of the road arm. The center or the roadwheel is located closer to

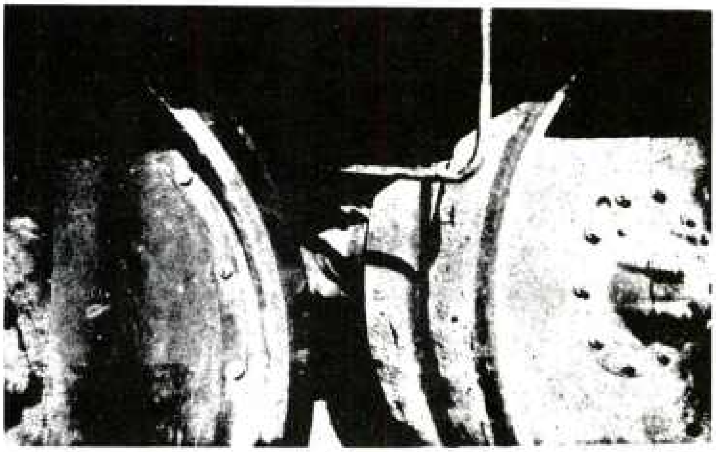


Figure 44   Installation of Road Arm Pot

the rear of the vehicle than is the road arm's pivot point. Since a 13" radius exists between the road arm pivot point and the center of the roadwheel, the initial angle of the road arm was 15°.

The instrumentation is shown in the track schematic, Figure 45. The pot has continuous mechanical rotation and 350° of electrical rotation. The 1.70 V_{dc} cal signal is equivalent to 27.5° of pot rotation from the rest position. This corresponds to the roadwheel moving up 6.2" or down 5.4" with respect to its rest position. These roadwheel displacements come from the relationship:

$$D = 3\frac{3''}{8} + 13'' \text{ SIN } (\theta_{POT} - \theta_0)$$

where

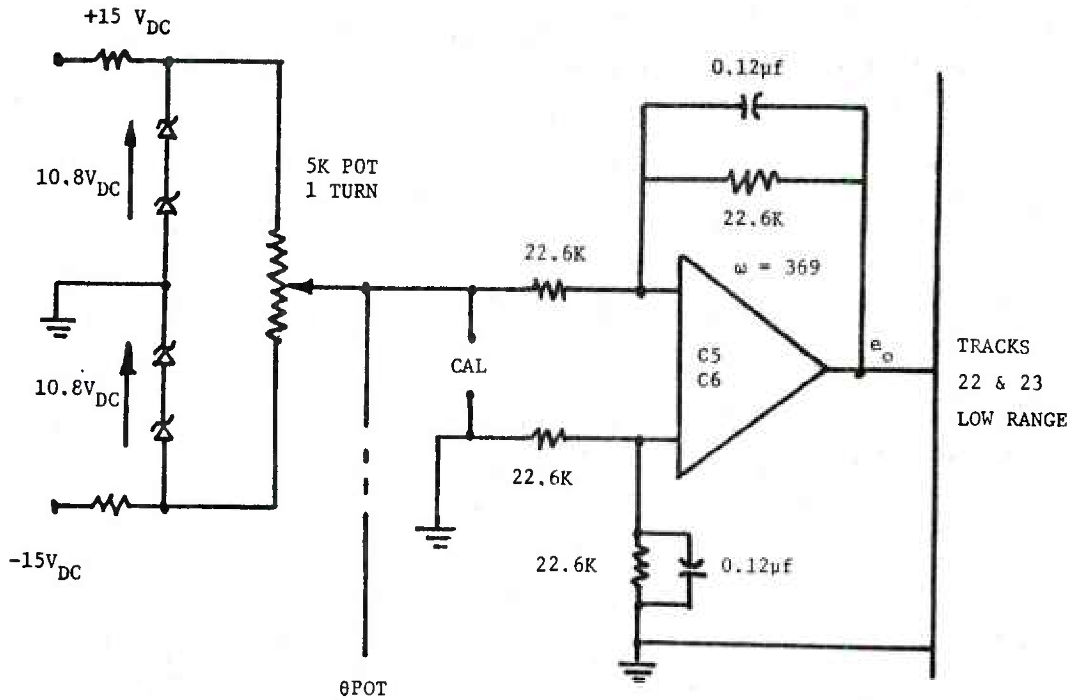
D = roadwheel displacement from rest position

θ_{POT} = pot rotation from rest position

θ_0 = 15° initial angle of road arm

The pot rotation and resulting roadwheel displacement are considered to be of opposite polarity with respect to the recorded track signal.

As previously shown in Figure 44 the cables coming from each pot were protected by conduit tubing. It has been recognized that this cabling was



CAL = 1.70 V_{DC}

= 27.5° POT ROTATION FROM REST POSITION

e_o = - WHEN ROADWHEEL MOVES TOWARDS THE HULL FROM ITS REST POSITION

TRACK 22 RIGHT ROADWHEEL VERTICAL MOTION

TRACK 23 LEFT ROADWHEEL VERTICAL MOTION

Figure 45

vulnerable to damage from debris being picked up by the tracks. The cabling was still intact at the end of the standard tests. The pots, however, were damaged very early in the tests by a combination of rocks, sagebrush and chicken wire. It was decided that enough bump course data had been accumulated and that the test schedule would not be delayed by the installation of the spare pots.

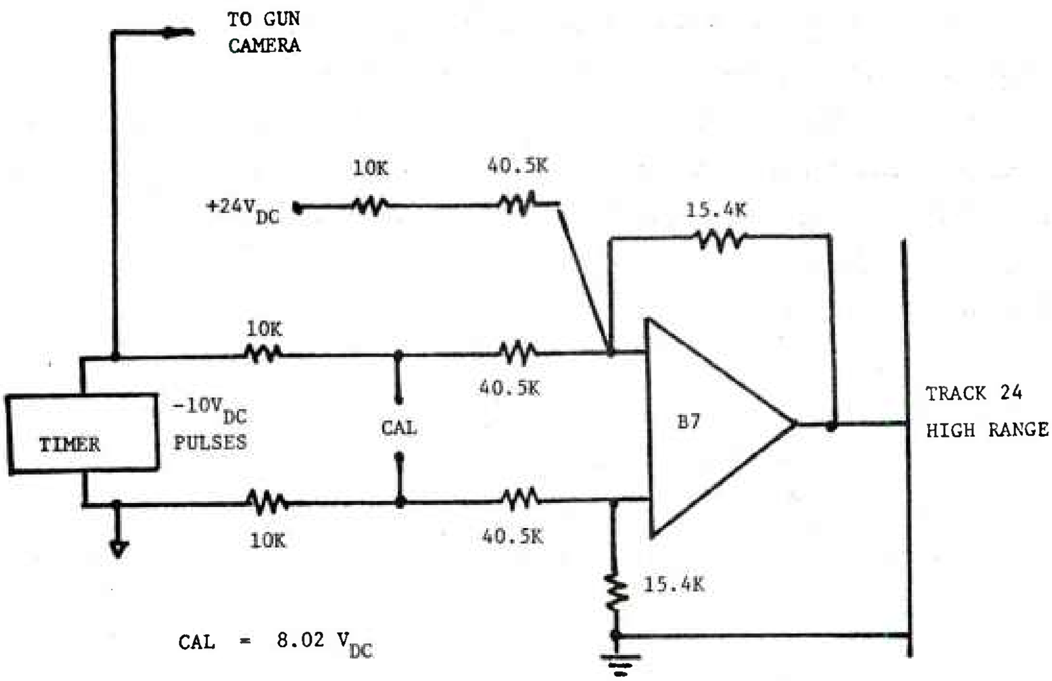
TRACK 24 TIMER AND TRIGGER PULL

As shown in the track schematic, Figure 46 this track combined the outputs of a timer and a V_{DC} signal that indicated when the gun was being fired. The output of the timer was a train of pulses spaced 0.1 sec apart (1.0 sec apart was also available). The timer pulses were used to time reference the tape recorder with the film in the gun camera. An integral camera lamp was used that flashed at the pulse train repetition rate. When the gun's trigger is pulled, the additional trigger pull signal will add a DC level to the pulse train.

The track scaling was based on a maximum instrumentation amplifier i input of 34 V_{DC}. Since the cal box supply was only 15 V_{DC}, the full scale input could not be simulated. The 8.02 V_{DC} cal signal was chosen to simulate the timer pulse amplitude. The track 24 FM record board was adjusted for a 13 1/3% frequency deviation at this level of input. The addition of the trigger pull signal would then overdrive the track by 13% which is within the capability of the recorder. Subsequent inspection of the data reveals that the timer was installed with reversed polarity with the result that the full dynamic range of the track was not used. There is no resulting loss of information since time rather than signal amplitude is of interest.

TRACK 25 DATA START SIGNAL

This track provided a signal that indicates the beginning and end of a recorded section of data. The procedure followed is illustrated in Figure 47. A step input was applied to track 25. After a short time delay, the test or calibration data was recorded. The data start signal was then removed after the end of the test. During the playback of the data, the presence of the data start signal is used to indicate the time duration that the test data is to be digitized. The track schematic Figure 48 shows the mechanization of the data start signal.



TRACK 24 TIMER AND TRIGGER PULL

Figure 46

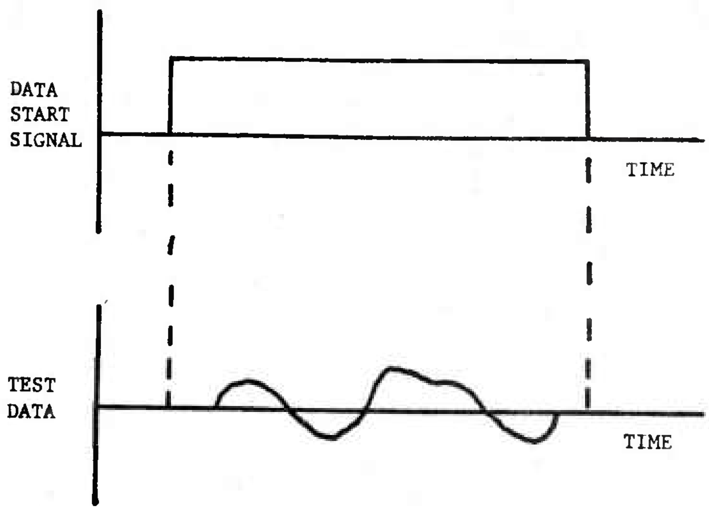
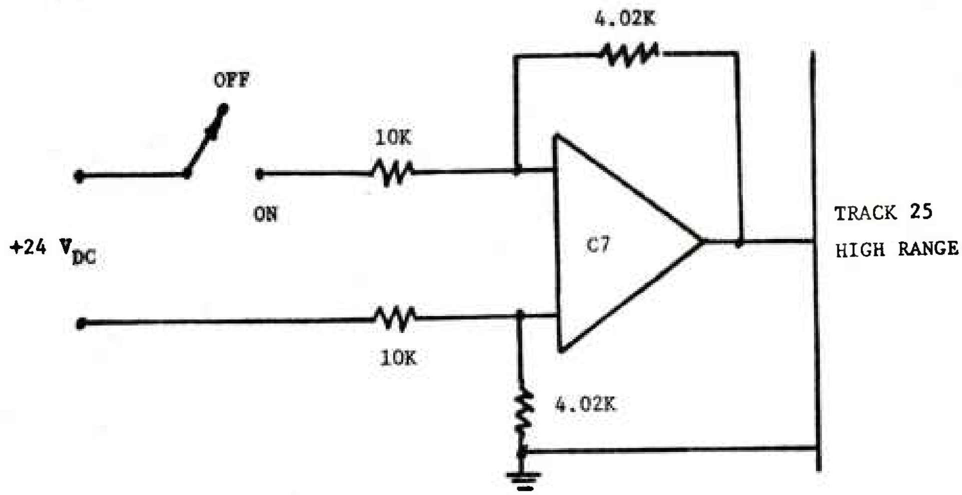


Figure 47

The tracks of tape recorder instrumentation are summarized in Figure 49. This figure represents the initial instrumentation set-up and does n not reflect the changes that occurred during the test. This figure, with subsequent changes, was used by the on-site technicians to keep in view the abundance of details regarding the instrumentation.

Figure 50 (pages 2-86 thru 2-93) illustrates the forms used for the instrumentation checkout procedure at the pre and post test calibration.



TRACK 25 DATA START SIGNAL

Figure 48

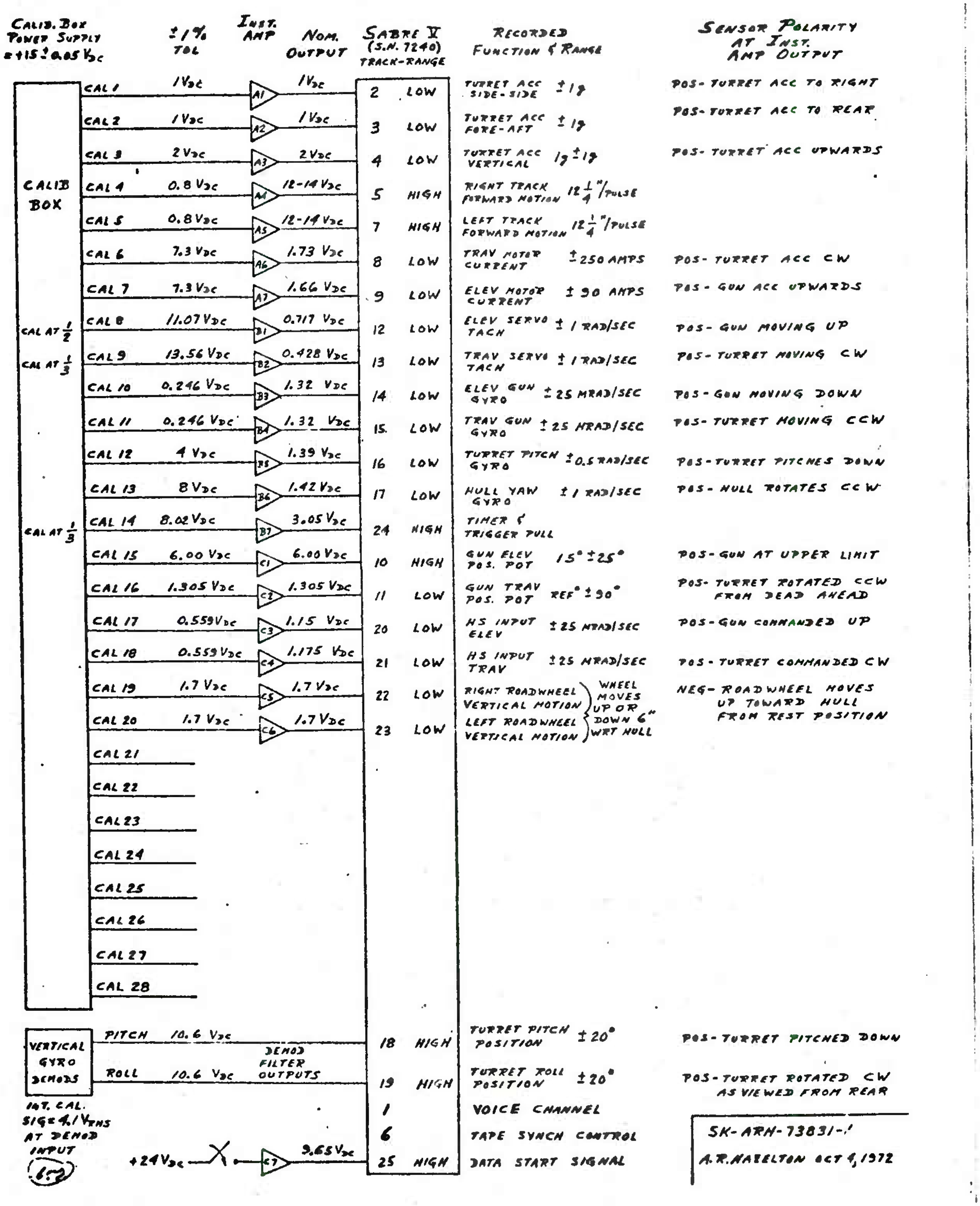


Figure 49 Instrumentation Calibration
(See Track Writeups for Final Scaling)

INSTRUMENTATION CALIBRATION

FOR

MICV-65 TEST SUPPORT

OF

HITPRO II VALIDATION

AT

YAKIMA FIRING CENTER

NAME:

DATE:

TIME:

PURPOSE OF CALIBRATION:

Figure 50

A. Instrumentation Amplifier Offset

With ±15 V_{DC} power applied to the inst amp boxes, short each amplifier input. Adjust each amplifiers offset adjust pot to null the amplifier's output voltage. Measure and record the resulting amplifier outputs.

INST AMP	OUTPUT VOLTAGE	INST AMP	OUTPUT VOLTAGE
A1		C1	
A2		C2	
A3		C3	
A4		C4	
A5		C5	
A6		C6	
A7		C7	
B1		D1	
B2		D2	
B3		D3	
B4		D4	
B5		D5	
B6		D6	
B7		D7	

B. Calibration Box Checkout

Apply ±15 V_{DC} power to the inst amp boxes. Connect cal box output banana jacks to their appropriate inst amp inputs. Apply floated 15 ±0.02 V_{DC} power to the cal box such that each inst amp output is positive with respect to amplifier ground when the calibrate toggle switches are in the POS and VALUE positions. Measure and record cal box supply voltage.

CAL BOX SUPPLY VOLTAGE =

Figure 50 (Continued)

Measure and record the cal box and inst amp outputs.

CAL BOX CHANNEL	CAL BOX OUTPUT	DRIVES INST AMP	INST AMP OUTPUT
CAL 1			
CAL 2			
CAL 3			
CAL 4			
CAL 5			
CAL 6			
CAL 7			
CAL 8			
CAL 9			
CAL 10			
CAL 11			
CAL 12			
CAL 13			
CAL 14			
CAL 15			
CAL 16			
CAL 17			
CAL 18			
CAL 19			
CAL 20			
CAL 21			
CAL 22			

Figure 50 (Continued)

CAL BOX CHANNEL	CAL BOX OUTPUT	DRIVES INST AMP	INST AMP OUTPUT
CAL 23			
CAL 24			
CAL 25			
CAL 26			
CAL 27			
CAL 28			
Vertical Gyro Pitch demod			
Vertical Gyro Roll demod			

Move the POS toggle switch to the NEG position. Check that the inst amp outputs have changed polarity.

C. SABRE V Calibration

With the cal box and inst amps connected per Part B, connect each inst amp output to its appropriate Sabre V track input. Unless otherwise specified, each FM record board should be adjusted for +40% and -40% center frequency deviations for the POS and NEG positions, respectively, of the calibrate toggle switch. Frequency deviations other than 40% are noted in the "comments" column of SK-ARH-73831-1. The center frequency of each FM record should be adjusted with the calibrate toggle switch in the ZERO position rather than using the TEST position on each FM record board. Calibration should be accomplished by adjusting each FM record board pot such that the test point value is equal to the head characteristic sheet value for 40% frequency deviation. Measure and record the following parameters.

Figure 50 (Continued)

INST AMP	DRIVES TRACK NO.	MEASURED VDC AT T.P.	-40% FREQ	CENTER FREQ	+40% FREQ
VOICE	1				
A1	2				
A2	3				
A3	4				
A4	5				
TAPE SYNCH	6				
A5	7				
A6	8				
A7	9				
C1	10				
C2	11				
B1	12				
B2	13				
B3	14				
B4	15				
B5	16				
B6	17				
V.G. PITCH	18				
V.G. ROLL	19				
C3	20				
C4	21				
C5	22				
C6	23				
B7	24				
DATA START	25				
	26				
	27				
	28				

Figure 50 (Continued)

D. Sensor Calibration

This part of the calibration procedure is concerned with checking those sensors that are not part of the installed stabilization system.

1. Turret accelerometers

Use a circular bubble level to orient each accelerometer's sensitive axis to sense ±1g and 0g's. Measure and record each accelerometer's response at the carrier amplifier's output.

	CARRIER AMP OUTPUT AT		
ACCELEROMETER	+1g	-1g	0g
Side-Side			
Fore-Aft			
Vertical			

2. Potentiometer Reference Voltages (Zener Regulated)

Measure and record the zener regulated reference voltages for the following potentiometers.

POTENTIOMETER	POS. REF.	NEG. REF.
Gun Elevation		
Gun Traverse		
Right Roadwheel		
Left Roadwheel		

3. Magnetic Pickups

The instrumentation amplifiers driven by the magnetic pickup outputs have been designed to operate in the following manner. With zero output from the magnetic pickups the outputs of each inst amp should be saturated at a negative voltage. This condition is caused by positive pot outputs driving the reversing inputs of each inst amp.

Figure 50 (Continued)

As the vehicle's drive sprocket's metal tabs pass by the magnetic pickups, the output of each inst amp should reverse to a saturated positive voltage and then return to a negative voltage as the tabs have passed the pickup. Ensure that the pot threshold input is adjusted for correct operation.

	CORRECT OPERATION	
Right Track	Yes	No
Left Track	Yes	No

4. Vertical Gyro

Vertical gyro input power comes from the output of the NOVA inverter. The NOVA's output voltage and frequency are to be held to 115 ±2.5 V_{RMS} and 400 ±5 Hz, respectively, while the inverter is loaded by the vertical gyro. Measure and record these parameters

NOVA output voltage =

NOVA output frequency =

Figure 50 (Continued)

2.4.3.3 Field Problems and Recommendations

Log books were used to record any field problems that temporarily affected the instrumentation or stabilization system. These books were given to the WECOM test director and should be used as reference material during the data reduction process.

With the experience of three months of field tests at the Yakima Firing Center, the following recommendations are made for any future tests of this type.

a. Test Equipment

Only ruggedized test equipment will survive the shock and vibration environment of a MICV-65 type vehicle. All equipment used for these tests met this requirement with the exception of the laboratory power supplies used for the instrumentation amplifiers. The original power supply and spare were mechanically damaged and later replaced with 15V batteries. A ruggedized DC power supply is the preferred method.

b. Test Schedule

A general rule of thumb seems to be that tests conducted under field conditions will require at least twice the time as if conducted under laboratory conditions.

c. Personnel

The sheer volume of detailed technical information needed to operate and maintain the stabilization system and 25 tracks of magnetic tape instrumentation requires the assignment of an on-site technician and engineer to the test program. It is extremely difficult for an engineer to troubleshoot a problem or check equipment operation via a long distance telephone call.

d. Weather

The middle portion of the tests was conducted under severe weather conditions, e.g. wind chills of -45°F on 7 December 1972. A few days later, the temperature increased enough so that 4" of snow could fall. A week later an additional temperature increase resulted in rain with the Yakima dusty soil turning into a sea of mud. Clearly these factors should be included in the scheduling of any future test programs.

e. Overtime

The use of a reasonable amount of overtime is well understood in order to maintain a test schedule. This test program had a late start but was still constrained by a rigid end date. All test personnel, both government and industry, worked 10 hours/day for periods of 14-15 consecutive days in order to meet the firm schedule. This action on their part was voluntary. Future test schedules should prevent the occurence of these simulated battle-field conditions.

2.4.4 Special Tests

The special tests were conducted after the conclusion of the standard testing phase. A two-week test period had originally been scheduled to perform these tests, but only 6 days remained until the end of the allowable time at the Yakima Firing Center. Some field time was saved by postponing the backlash test to be done at General Electric's facility since this test did not involve any gun firing.

2.4.4.1 Gun Receiver Motion and Vehicle Reaction Tests

The purpose of these tests was to measure and record the profile of the gun receiver motion during gun firing and also the resulting motion of the vehicle's hull as a reaction to the gun firing. These tests were conducted using the following gun firing rates.

a. A series of 5 single shots

b. Five-round bursts at a controlled rate of approximately 200 rounds/min.

c. Five-round bursts at a fully automatic rate of approximately 600 rounds/min.

As shown in Figures 51 and 52 the profile of the gun receiver motion was measured by attaching the shaft of a linear motion potentiometer to the gun receiver by means of a clamping fixture. The body of the pot was mounted on a tripod fixture which was clamped to the rear of the gun housing. The pot chosen was a Bourns Model 157 pot which has 1 3/8" of linear travel. This pot was chosen for its ability to withstand an acceleration of 100 g's or a 40 g vibration at 20-2000 HZ without an electrical discontinuity greater than 0.5%. The self-aligning feature of this pot is also necessary in order to prevent damage to the pot from misalignment of the axis of the pot shaft with the axis of receiver motion.

The measurement of the gun receiver motion was recorded on track 7 as shown in the track schematic, Figure 53. With the receiver at its

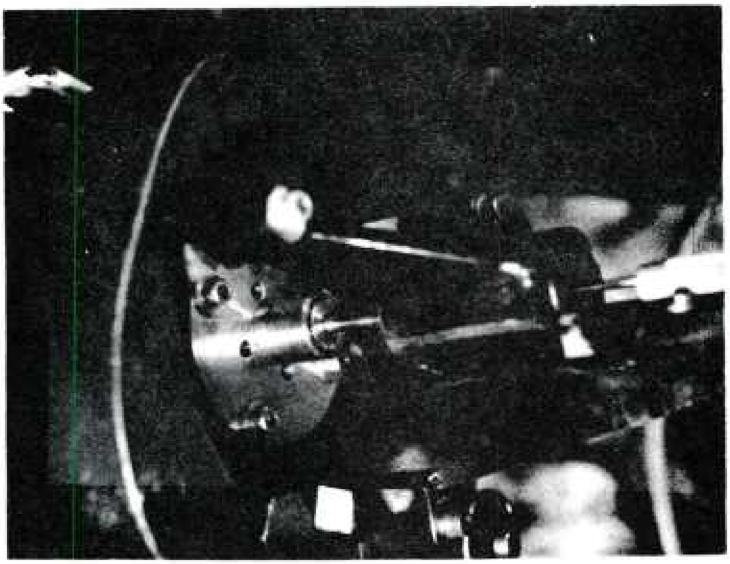


Figure 51 Pot Measuring Gun Receiver Motion

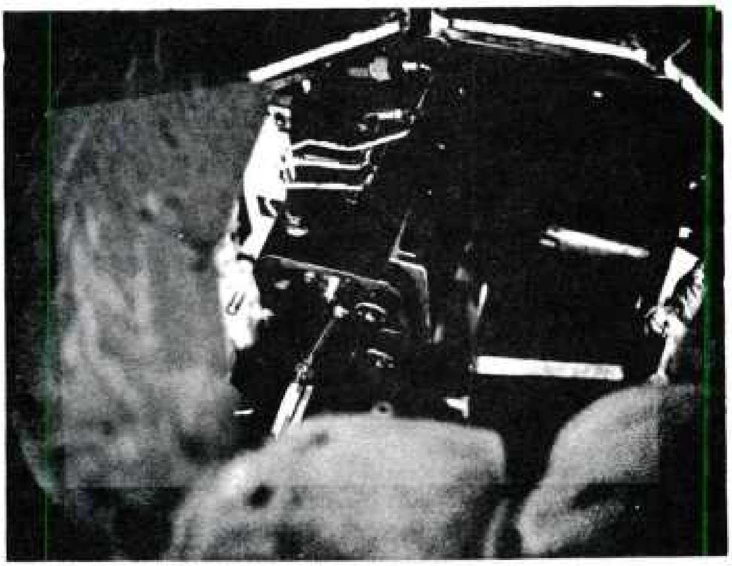
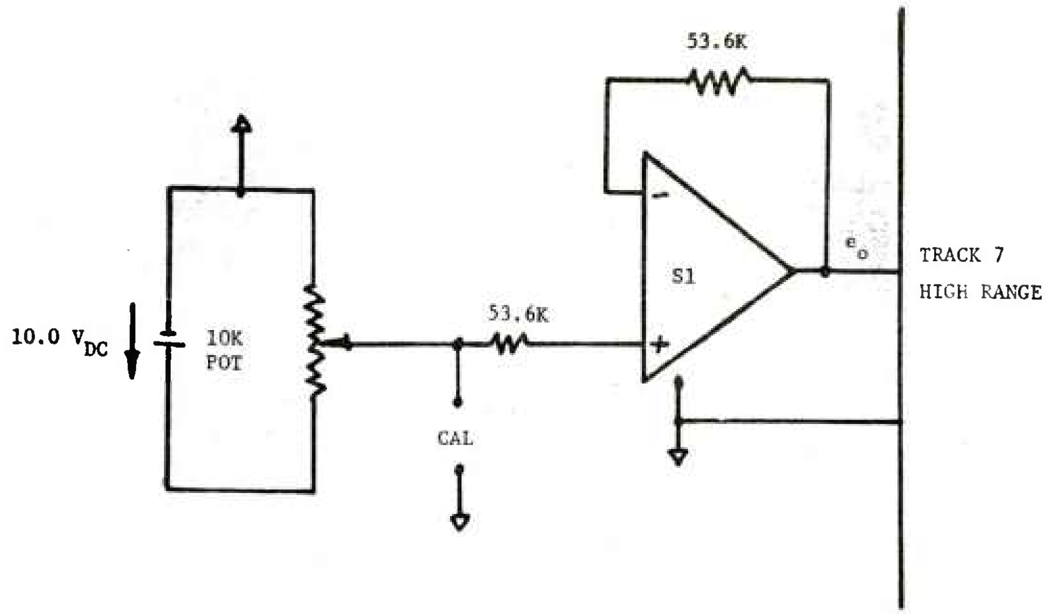


Figure 52 Pot Measuring Gun Receiver Motion



CAL = 10 V_{DC}

= 1.375" OF RECEIVER TRAVEL

e_o = INCREASINGLY POSITIVE AS RECEIVER MOVES TO THE REAR

e_o = + 0.488 V_{DC} (0.067") AT RECEIVER'S REST POSITION

TRACK 7 GUN RECEIVER MOTION

Figure 53

rest position, the amplifier output of +0.488 V_{dc} corresponds to the pot shaft being set at 0.067" less than its fully extended travel. This allowance is necessary since some forward receiver motion exists at the instant of shell impact.

The hull motion resulting from gun firing was measured by using the hull yaw gyro to monitor the rotational rate of the hull. As shown in Figure 54, an adapter bracket was used to reorient the gyro's input axis so that the hull's pitch rate was measured while the gun was fired in the dead ahead position. Figure 55 shows the gyro and bracket reoriented again so that the hull's roll rate was measured while the gun was fired 90° to the side.

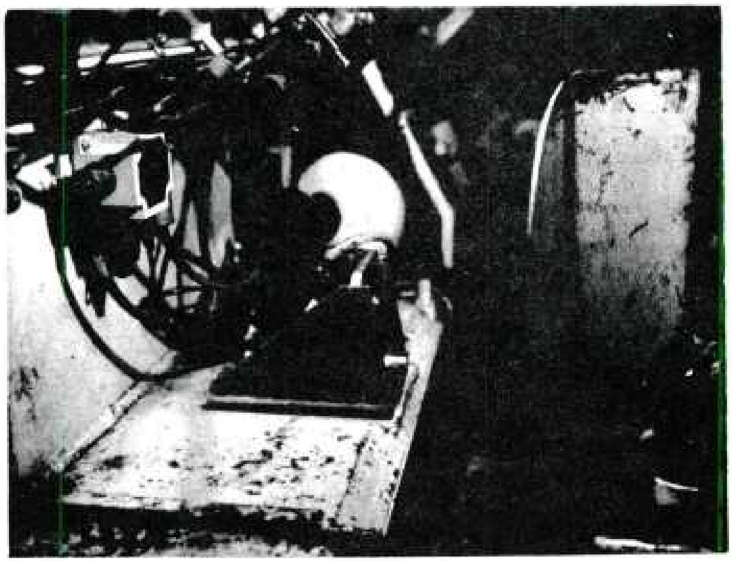


Figure 54 Hull Yaw Gyro Measuring Hull Pitch Rate

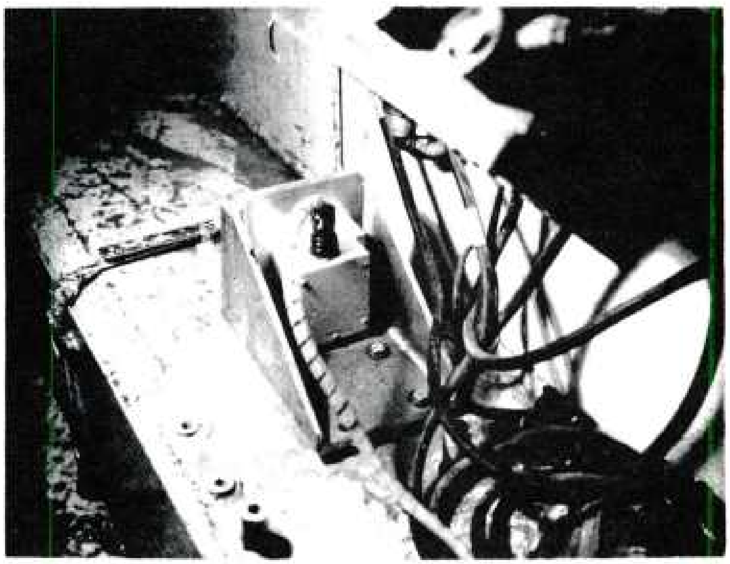


Figure 55 Hull Yaw Gyro Measuring Hull Roll Rate

Since these tests were only concerned with gun and vehicle reactions to gun firing, the vehicle was parked on a concrete pad at the firing range for these stationary vehicle tests. The instrumentation used for the standard tests was modified in the following manner for the gun receiver motion and vehicle reaction tests.

Tracks 1, 2, 3, 4, 6, 24 and 25 were unchanged from the conditions existing at the end of the standard tests. Tracks 5, 10, 11, 20, 21, 22 and 23 were omitted for these tests.

Tracks 8, 9, 12 through 19 were rescaled by changing the instrumentation amplifier gains, the calibration signals and readjusting the FM record boards for a 40% deviation at each new level of amplifier output. The signal polarities remain unchanged from the standard tests. Other changes were also made to these tracks. Tracks 12 and 13 were calibrated at the full 40% frequency deviation rather than the reduced deviation used furing the standard tests. The Track 14 and 15 filter capacitors were removed with the result that the true inertial gun velocities were being recorded. The results of these changes are listed in Table 1 which reflects the existing scaling before the first shot was fired.

TABLE 1 RESCALED TRACKS FOR SPECIAL TESTS

TRACK	SIGNAL	CALIBRATION SIGNAL
8	Traverse Motor Current	57.9 amps
9	Elevation Motor Current	63.0 amps
12	Gun Elevation Velocity	99.3 mrad/sec
13	Gun Traverse Velocity	103. mrad/sec
14	Gun Elevation Velocity	66.7 mrad/sec
15	Gun Traverse Velocity	30.2 mrad/sec
16	Turret Pitch Velocity	96.3 mrad/sec
17	Hull Angular Velocity	48.1 mrad/sec
18	Turret Pitch Angle	33.0 mrad
19	Turret Roll Angle	33.0 mrad

The following test runs were made with the stabilized power drives in the travel mode of operation and the magnetic tape recorder operating at a 15 ips recording speed.

Run S1

Test Conditions: Gun dead ahead at 0° elevation

Track 17 = Hull pitch velocity

(Positive tape output represents the front of the vehicle pitching down)

One test shot was fired to check the amplitude scaling of the instrumentation. The gun receiver motion visicorder trace looked good, but the trace of the hull pitch velocity was too small. Track 17 was then rescaled by changing only the input resistors on the B6 inst. amp. from 100K to 30.1K. This change causes the original cal signal to now represent 14.5 mrad/sec rather than 48.1 mrad/sec. A second test shot verified that the amplitude of this track signal had been increased to a satisfactory level.

Data was then recorded with the gun being fired at the standard firing sequence of single shots, controlled rate and fully automatic rate. Figures 56 and 57 show the results of gun firings at controlled and fully automatic rates. The visicorder traces of the hull pitch velocity show that a small DC offset existed in the output of the hull yaw gyro's demodulator electronics. When the hull pitch velocity is numerically integrated to yield a time function of hull pitch angle, a constant velocity or ramp of angle should be used to force the net hull pitch angle to be equal to zero at the end of the hull's motion.

Run S2

Test Conditions: Gun over right side of vehicle at 0° elevation

Track 17 = Hull roll velocity

(Positive tape output represents the hull rotating CW as viewed from the rear of the vehicle)

This test run was started by firing a series of five single shots. The subsequent playback of track 17 showed a large amplitude, 120 - 125 Hz

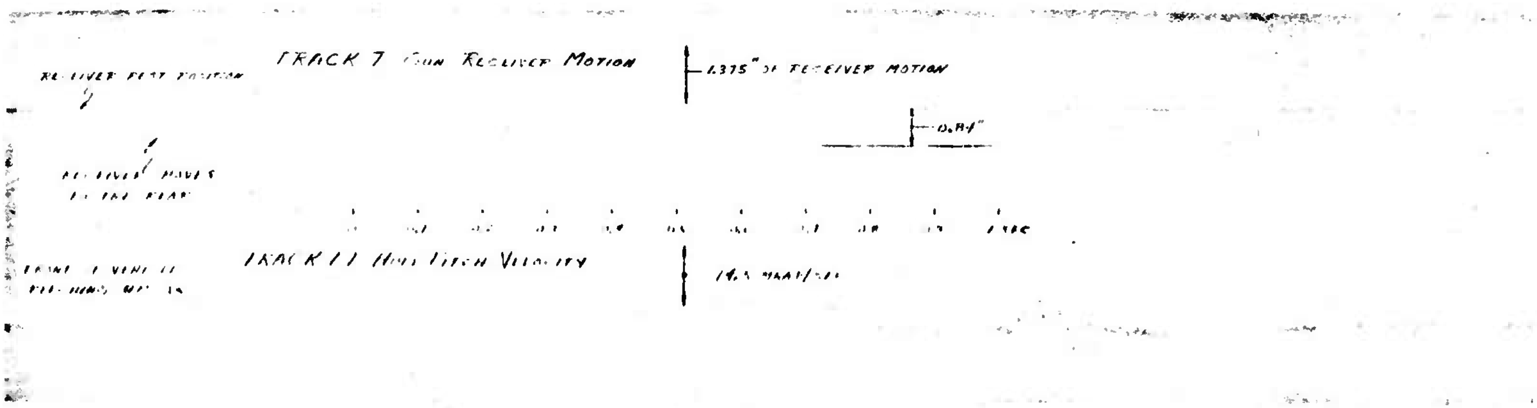


Figure 56 Five Round Burst at Controlled Rate of 180 Rounds/Minute

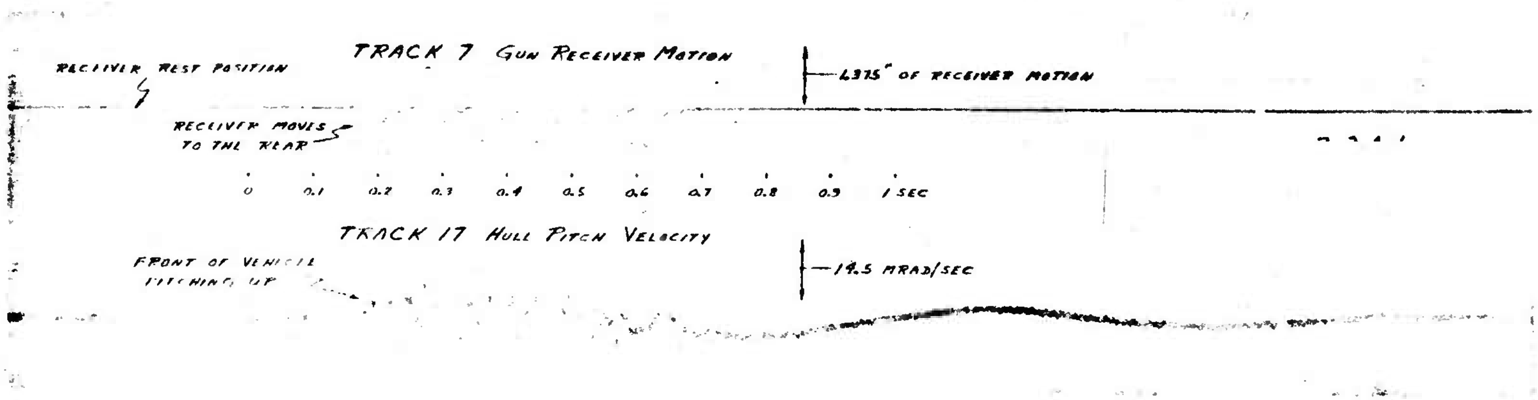


Figure 57 Six Round Burst at Fully Automatic Rate of 680 Rounds/Minute

vibration that was overdriving the tape recorder electronics. After the vibration had transiently decayed, the low frequency hull roll motion was clearly displayed. The source of the high frequency vibration was not immediately evident. The test run was continued through the standard firing sequence in order to record the low frequency hull roll motion. Track 17 scaling throughout the run was 14.5 mrad/sec full scale.

Run S3

Test Conditions: Same as Run S2

This test was a rerun of Run S2 with track 17 rescaled back to 48.1 mrad/sec full scale. The purpose of this change was to reduce the recorded level of the high frequency vibration at the expense of lowering the amplitude of the low frequency hull roll motion. In this manner a total picture of the hull roll motion can be reconstructed by combining information from the two test runs.

Runs S4 and S5

Runs S2 and S3 were concerned with test results when the gun was fired over the right side of the vehicle. Runs S4 and S5 were conducted with the gun fired over the left side of the vehicle at 0° elevation. The track 17 scaling of 48.1 mrad/sec was continued for Run S4 while it was rescaled back to 14.5 mrad/sec for run S5. A shortage of ammunition required that fewer rounds be fired at each firing rate for these tests.

At the end of these tests a short investigation was made to find the source of the high frequency vibration when the hull yaw gyro was reoriented to measure the hull roll rate. The source was eventually found by tapping the gyro's adapter bracket with a hammer and noting that a 110 - 115 Hz damped sinusoid resulted at the gyro's output. Referring to Figure 55 it can be seen that the adapter bracket was mounted to the seat by two bolts near the right edge of the bracket. The left end then became essentially a cantilevered beam with a resultant natural frequency that was excited during gun firing. The low frequency hull roll rate can be extracted from the track 17 recordings by using a filter to eliminate this high frequency vibration.

2.4.4.2 <u>Gun Recoil Force and Barrel Whip Tests</u>

a. Gun Recoil Force Test

The purpose of this test was to measure the gun recoil forces appearing at the elevation trunnions during gun firing. Expected forces were in the range of 5000 - 7000 pounds. The test method chosen was to measure the rearward displacement of each elevation end shield from the turret casting when the gun was fired. A hydraulic jacking mechanism would then be used to find the jacking force, between each end shield and turret, that would create the same rearward displacement. In this manner the gun recoil force at each trunnion could be found.

As shown in Figures 58 and 59 a polished metal mirror was mounted on the forward side of each end shield. A probe containing 600 strands of glass fiber optics was clamped in a probe mount that was welded to the turret casting. Half of the fibers transmit light which, after being reflected from the metal mirror, is captured by the remaining 300 fibers and translated into an analog output signal. The non-linear characteristic curve of these fotonic sensors is shown in Figure 60. The useable portion of the sensor's characteristic curve is the linear region where the probe is positioned 20 to 40 mils away from the reflecting surface. For these tests the probe was positioned 30 mils from the metal mirror.

The measurements of the two end shield motions were recorded on tracks 8 and 9 as shown in the track schematic Figure 61. The negative output of the fotonic sensor at the 30 mil position was nulled by adjusting the 10k pot to supply an equal and opposite voltage. In this manner, when the gun was fired, only the additional incremental voltage from the sensor would be amplified to provide a large signal for recording purposes.

The gun recoil force test (Run S6) was conducted on 20 December 1972 which was the last allowable day of testing. Test data was accumulated with the gun being fired dead ahead at 0° elevation. The track 8 and 9 test data is full of 60 Hz noise since the only 115V, 60 Hz power supply available for the fotonic sensors was a portable gasoline driven generator.

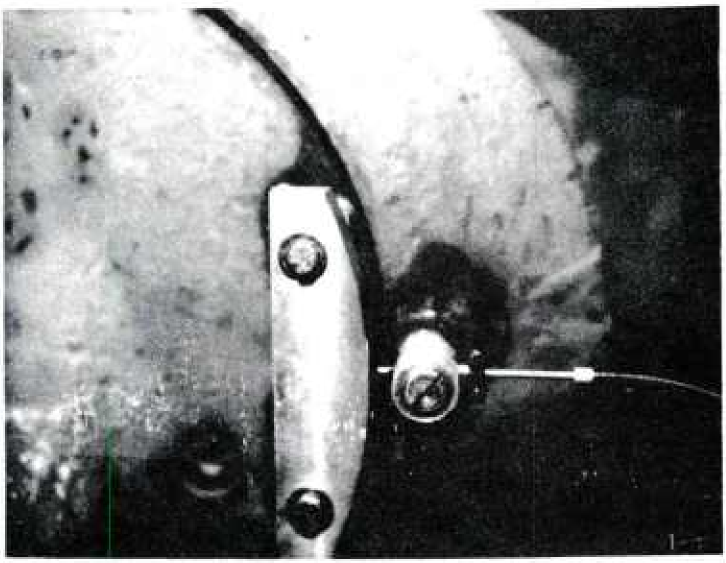


Figure 58 Fotonic Sensor
Sensing Right End Shield Motion

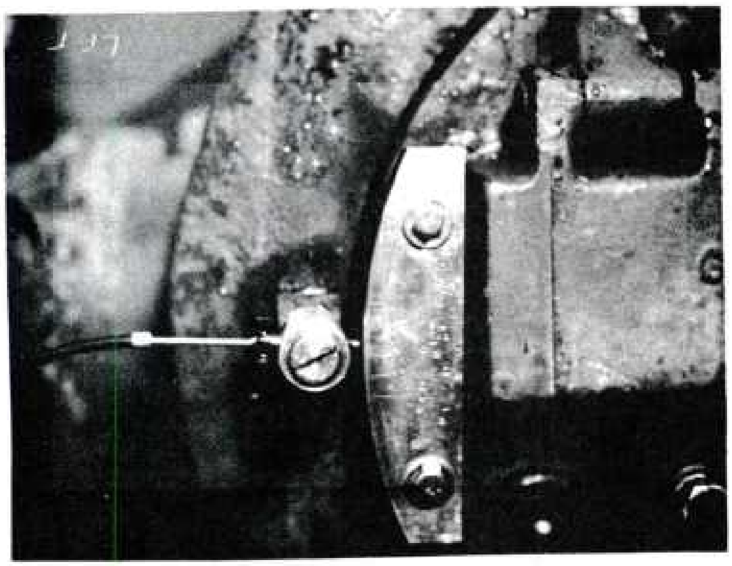


Figure 59 Fotonic Sensor
Sensing Left End Shield Motion

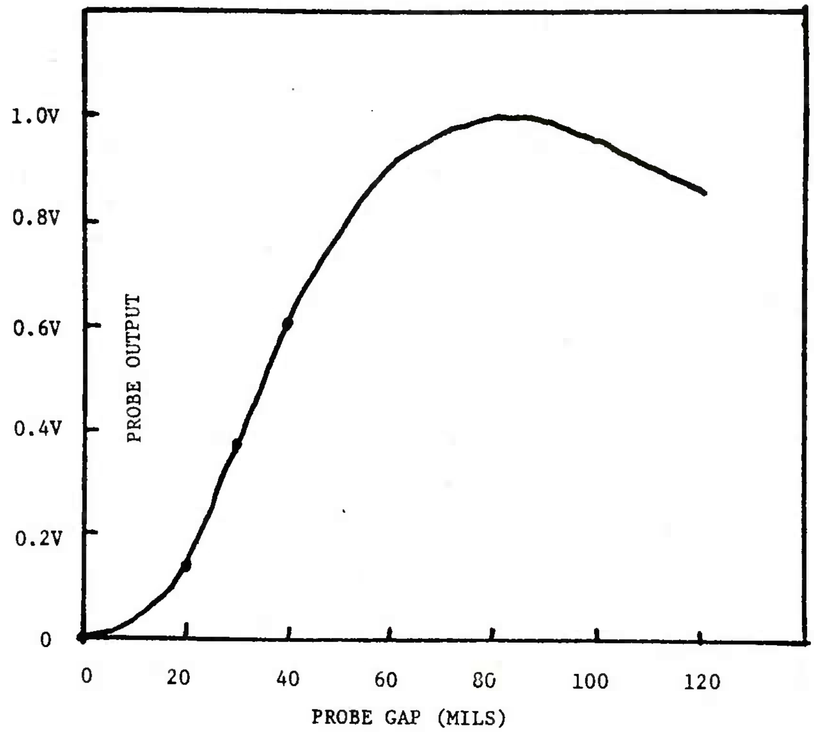
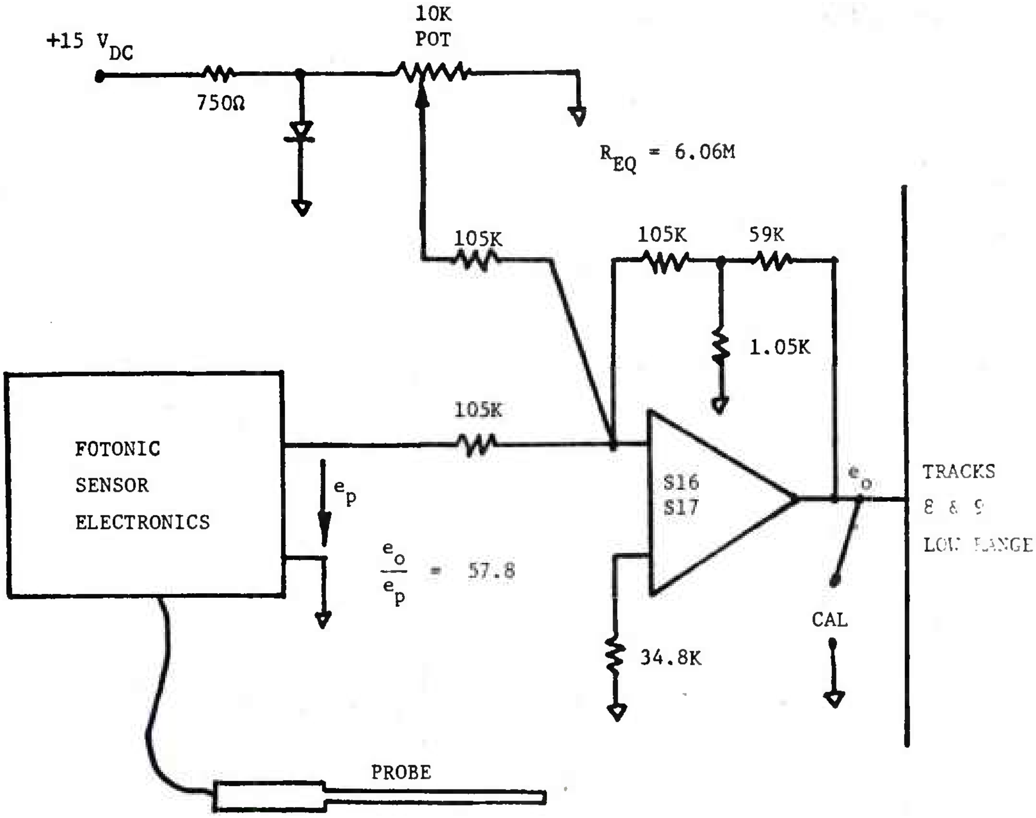


Figure 60 Fotonic Sensor Characteristic Curve

Proper operation of these fotonic sensors demands that the instrument be properly connected to a power supply that has a good earth ground. Several hours were spent, in a race against time, to try to effect this ground under field conditions of a windy, cold rain and a sea of mud surrounding the vehicle. The attempt was unsuccessful in the time allowed.

Some data may be salvaged from this test if the 60 Hz noise can be filtered out of the sensor data. During the test the output of the left sensor was monitored with a digital voltmeter. The sensor's output was identical before and after each shot was fired. This



CAL = 1.97 V_{DC} = 1.44 MILS (RIGHT), e_p = 42.3 MILS/V

= 2.00 V_{DC} = 1.73 MILS (LEFT), e_p = 50 MILS/V

e_o = + END SHIELD MOVES REARWARD

TRACK 8 RIGHT END SHIELD MOTION

TRACK 9 LEFT END SHIELD MOTION

Figure 61

indicates that the elevation end shield was always returning to its original position and not assuming a random position within any bearing looseness.

Another method that might be used to indirectly obtain the recoil force data is to use the results of the gun receiver motion test. Two cascaded high pass filters can be used to approximate the second derivative of the gun receiver recoil position. This acceleration times the mass of the receiver will approximate the gun recoil force.

b. Barrel Whip Test

A gun stabilization system essentially stabilizes only the breech end of the gun. Since the gun barrel vibrates or whips during firing, an additional error source is created with regard to round impact. This test was designed to measure the angular bending near the end of the gun barrel during gun firing.

The method of instrumentation used was to mount four accelerometers near the end of the gun barrel as shown in Figure 62. The vertical whipping motion of the gun barrel was to be measured by the two accelerometers mounted on top of the small aluminum mounting blocks. The accelerometers would have to be carefully aligned and calibrated in an attempt to form a matched pair. During gun firing any barrel bending between the accelerometer mounting positions would cause the two accelerometers to have unequal outputs. The data of primary interest would be the difference of the two measured accelerations. This data together with the distance between accelerometer centerlines and the rigid body angular acceleration of the gun (differentiation of gun gyro recording) could be used to find the angular acceleration of one accelerometer with respect to the other. Numerical double integration of this data would yield the angular whipping motion of the gun barrel between the sensor mounting positions. The side mounted accelerometers were to be used to measure the horizontal whipping motion.

The accelerometers used for this test were the Statham Model A514TC which uses a gas damping technique to achieve a high frequency response capability. These accelerometers are capable of measuring 25 g's and surviving 200 g's.

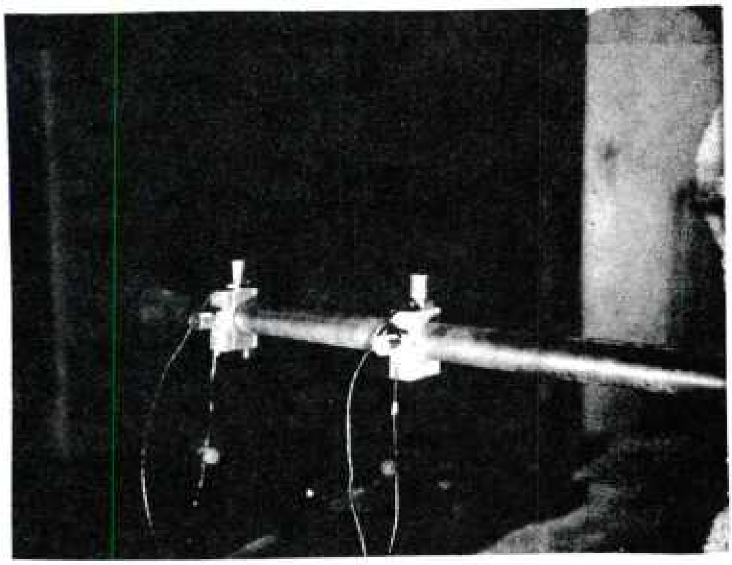


Figure 62 Mounted Accelerometers for Barrel Whip Test

The barrel whip test, as designed, was never performed. One accelerometer was defective as it came from its shipping carton. Two accelerometers could not survive preliminary tests to determine expected g loading. The last accelerometer did not survive the first shot fired at the test range. Subsequent conversation with the accelerometer manufacturer reveals that they had a problem of long-term gas leakage in this model. It is reasonable to expect that this was the reason for the failures.

2.4.4.3 <u>Gear Train Backlash and Windup Tests</u>

The amount of backlash existing in the power drive gear trains of a stabilization system is important to the gunner since it represents an apparent deadband when he attempts to stay on a target by making small positive and negative gun angle corrections. The purpose of these tests was to determine the backlash and gearing windup in the traverse and elevation power drive gear trains at torque levels typically imposed by small angle corrections made by a gunner.

A simplified description of the test technique is shown in Figure 63. Assume that the motor and load are initially at rest. Upon application of a command input the motor shaft rotates, successive gear meshes come into contact as they pass through their respective backlash until firm contact is made at the last mesh and the load starts to move. The load then follows the motor until the motor is commanded to reverse direction. At this time the load will stop and the previous process is repeated as the motor passes through its backlash in the opposite direction. The backlash measurement is made by integrating the difference of the motor and load velocities which is equivalent to measuring motor angle rotation while the load has stopped.

For the backlash tests the usual power drive command signal from the gunner's handstation was replaced with a function generator input so that the turret (traverse test) and gun (elevation test) could be oscillated in a controlled manner with a 0.25 Hz sine wave order at several levels of commanded velocity and resultant required torque.

b. Traverse Backlash Test

The traverse motor shaft velocity was measured by using the power drive servo's motor speed tachometer. The load velocity was measured by using an instrumentation tack mounted inside the turret as shown in Figures 64 and 65. The spring-loaded tach mounting fixture is rotated in Figure 64 to show the fixture's construction and the rubber O-ring around the extension of the tach shaft. Figure 65 shows the fixture in its test position with the O-ring in firm contact with the bearing cover.

Figure 66 shows the instrumentation used to measure the traverse backlash. The servo's motor tach output is fed into a constant gain amplifier, S10. The output of the load tach is fed into a variable gain

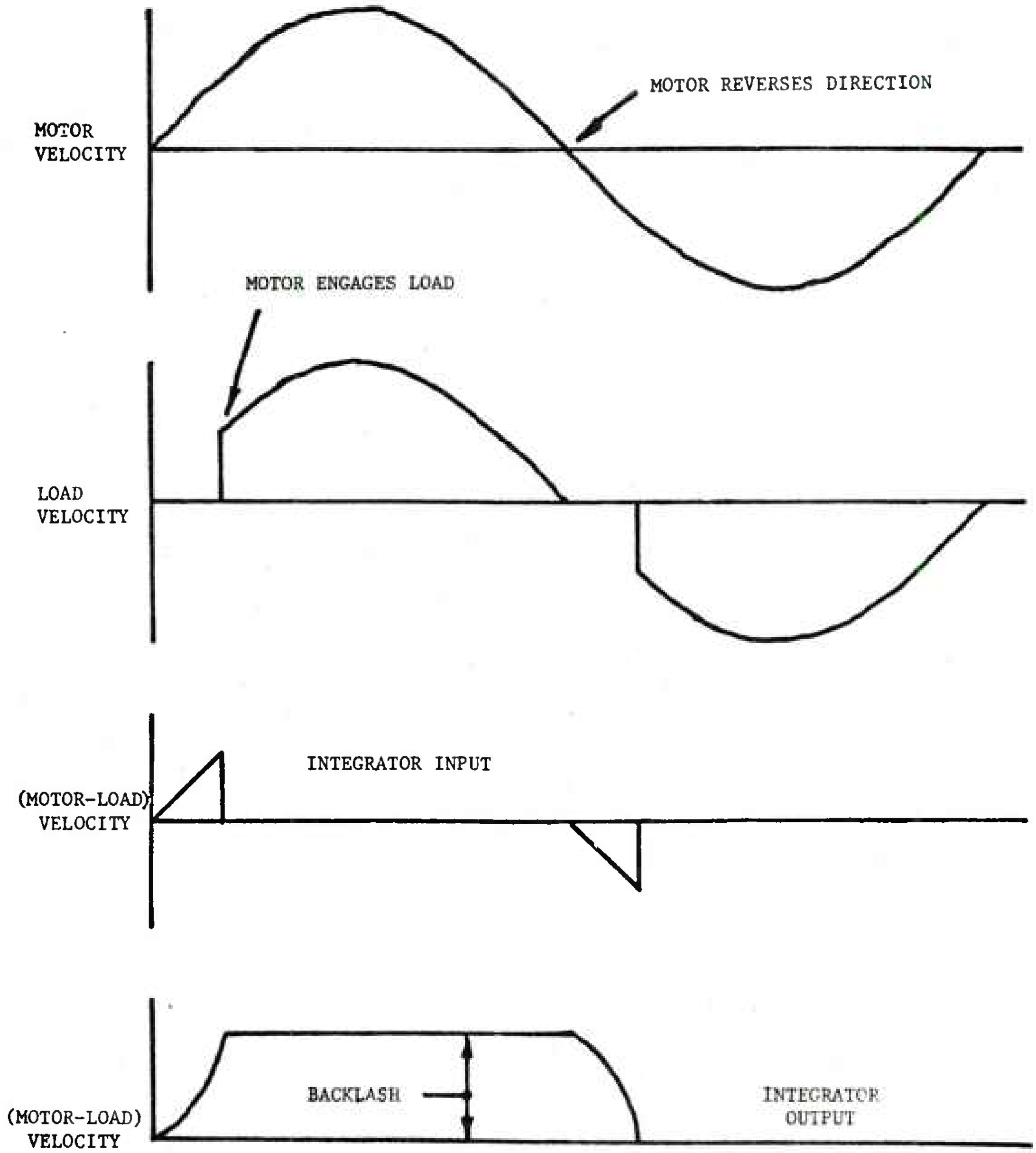


Figure 63 Test Technique for Backlash Measurement

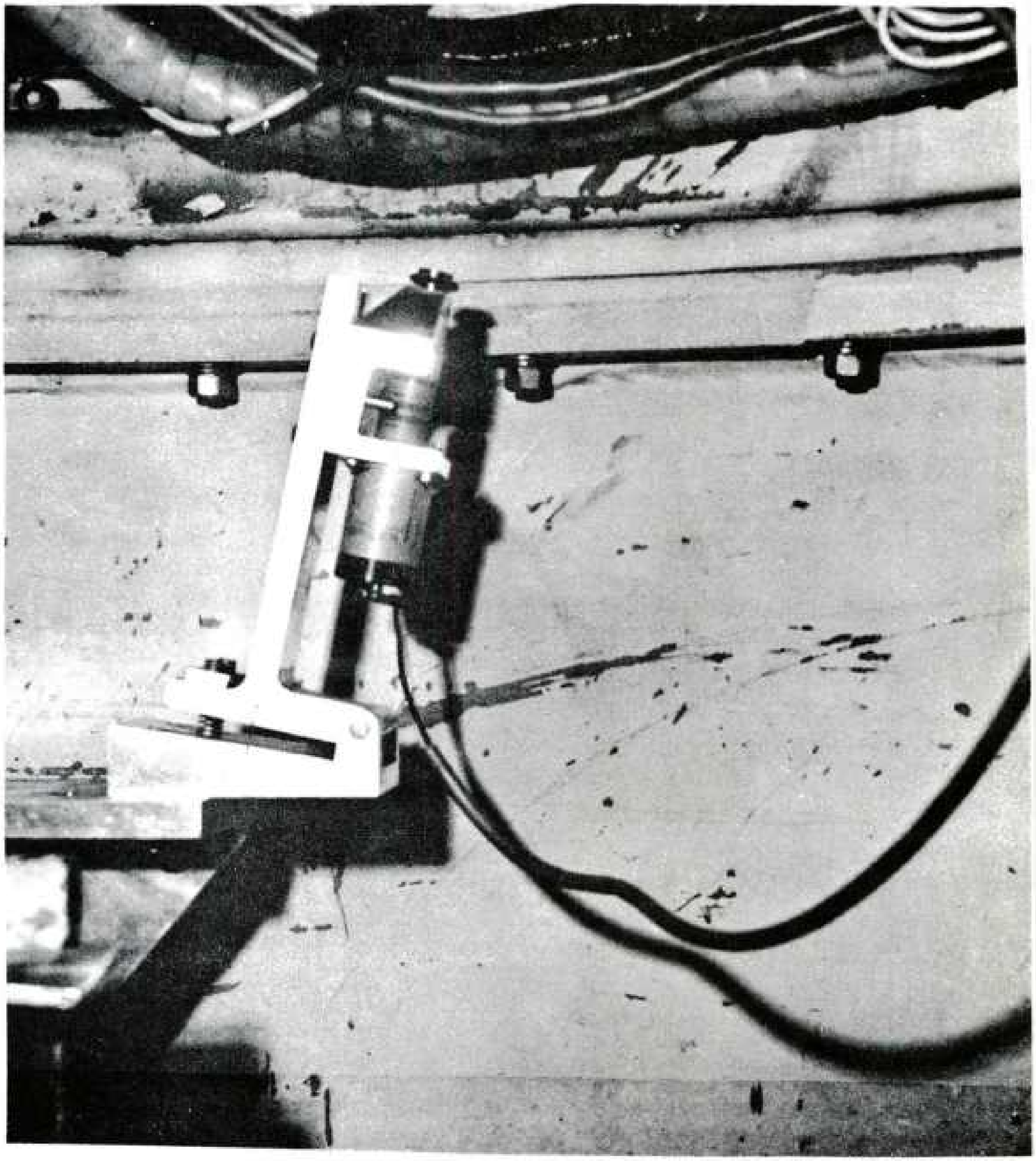


Figure 64   Traverse Load Speed Tach (Rotated)

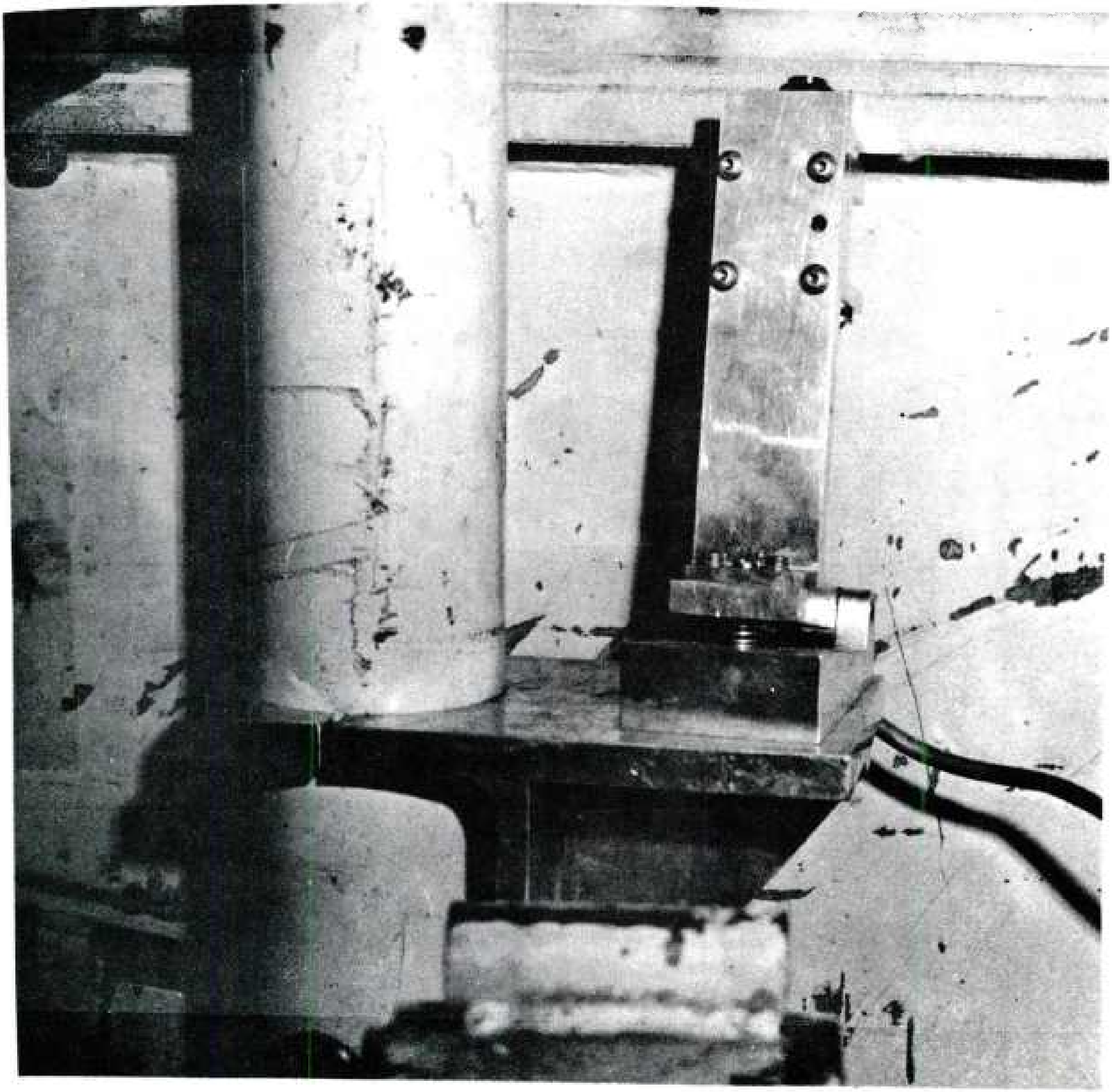


Figure 65 Traverse Load Speed Tach (Test Position)

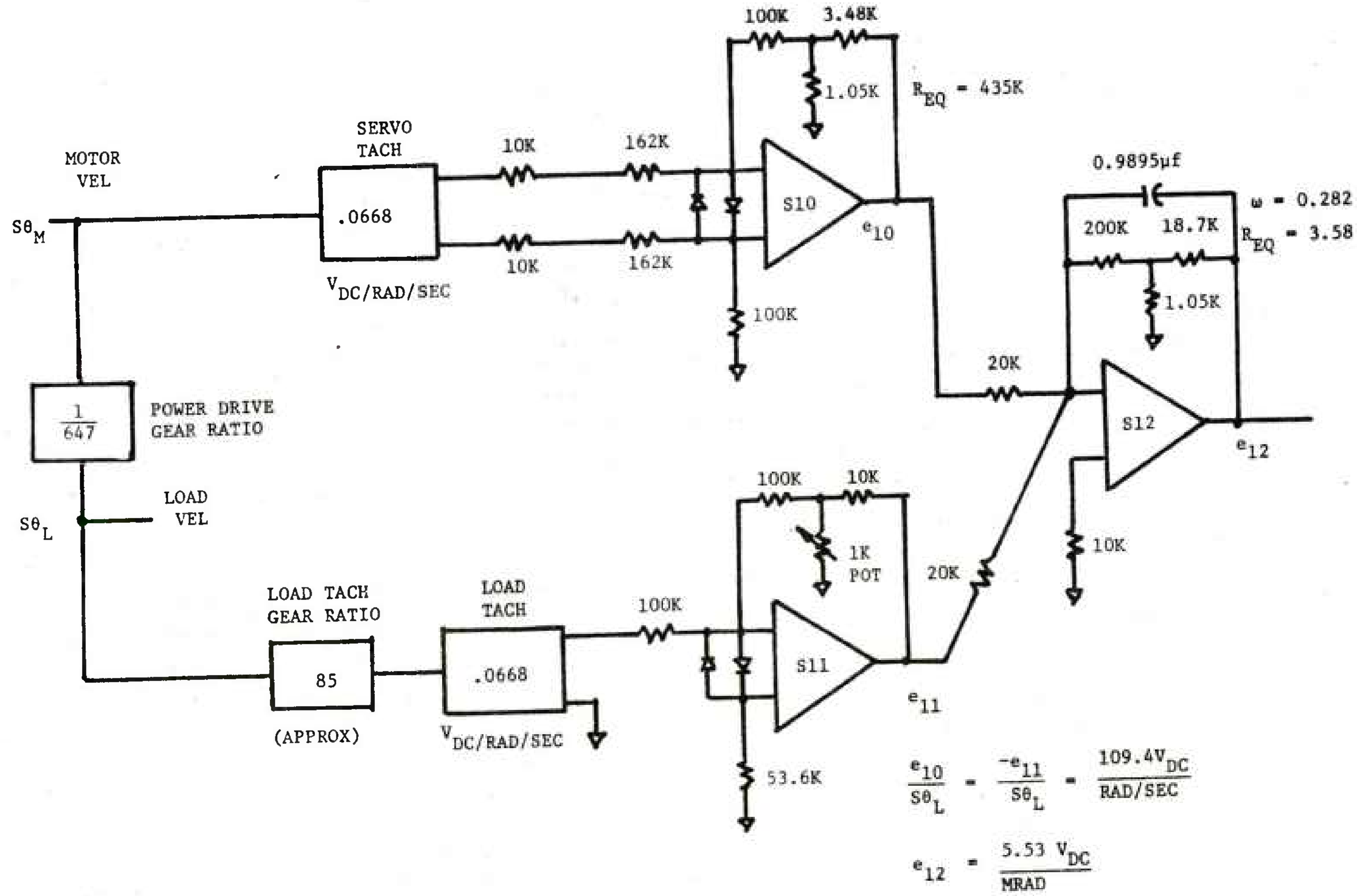


Figure 66 Instrumentation - Traverse Backlash Test

amplifier, S11, which has a pot in its feedback path. This adjustment was provided so that the two amplifier outputs could be made to be identical when the motor and load were moving together. The outputs of the two tachs were wired in a manner that produced opposite polarity signals at their respective amplifier outputs. These two signals were then summed at the input of integrator S12 whose output is proportional to the difference of the motor and load positions. The outputs of these three amplifiers plus motor current and handstation input signals were recorded on a visicorder oscillograph to provide the test data.

The results of the test conducted at the largest magnitude of hand-station input provide the best visual data of the mechanism of backlash. Figures 67 and 70 show the motor and load velocities plus the handstation input at two different recorder speeds. Figures 68 and 71 show the motor current signal.

When the handstation input becomes zero volts the motor shaft and load both come to a dead stop. The motor then builds up torque to overcome the motor shaft friction. The motor shaft then rotates through the backlash of the first gear mesh. Additional torque is then repaired to overcome the friction of this mesh and the succeeding meshes as they are contacted. Finally, the load is contacted after the motor shaft has passed through all the individual backlash components. The load starts to move as the current rises to a peak level to provide the breakaway torque. The motor and load are accelerated and then pass through a fairly constant velocity region while the current undershoots its running torque level. The load then resumes its sinusoidal motion in response to the handstation input.

The backlash measurement is shown in Figures 69 and 72. The sharp trace reversals that end at each initiation of load motion are the combined measurements of backlash and gear train windup. The average measurement for this test run was 0.142 mrad referred to the load. The average of the left and right measurements are used since different gear teeth are involved at the two ends of turret travel during the sinusoidal

Figure 67 Traverse Backlash Test (Run 4)

Figure 68 Traverse Backlash Test (Run 4)

Figure 69 Traverse Backlash Test (Run 4)

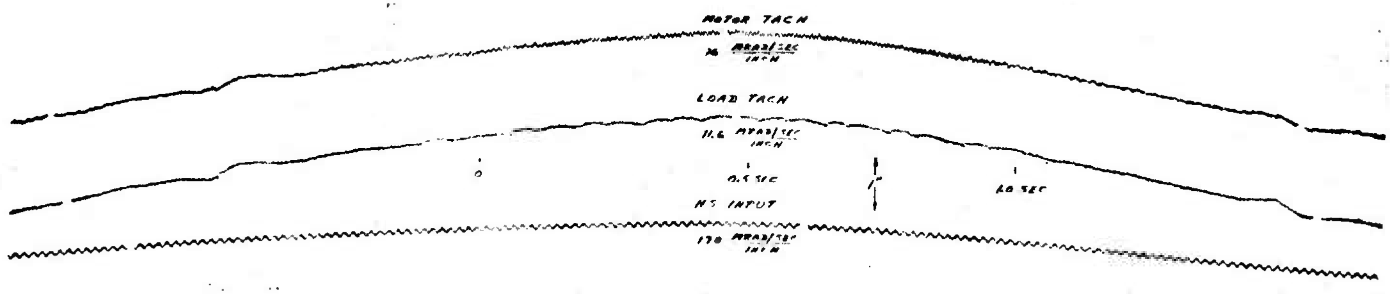


Figure 70 Traverse Backlash Test (Run 4)

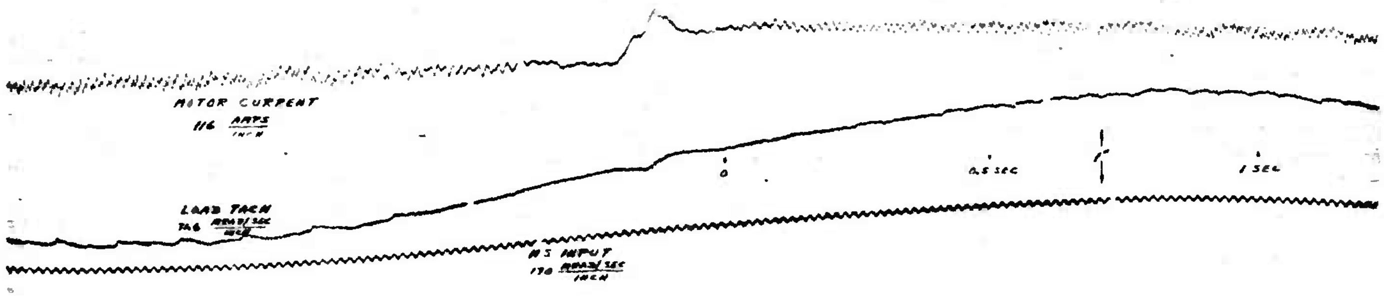


Figure 71 Traverse Backlash Test (Run 4)

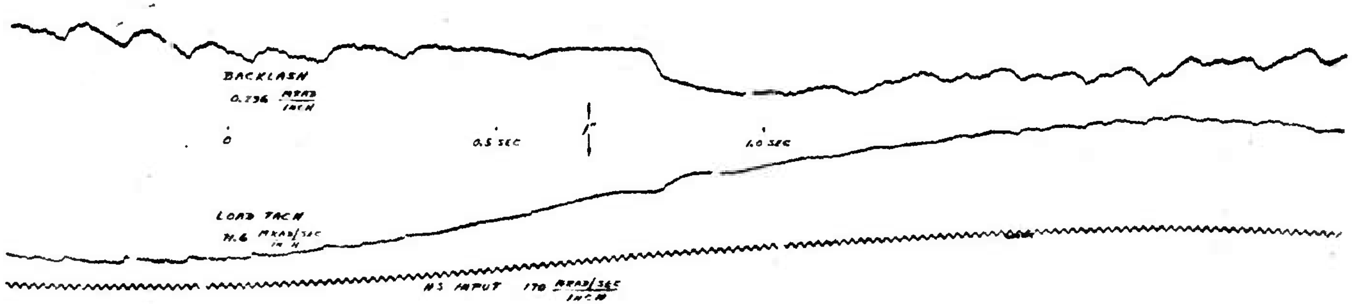


Figure 72 Traverse Backlash Test (Run 4)

motion. Test results for a lower level of handstation input are presented in Figures 73 to 75. The average backlash and windup measurement for this run is 0.112 mrad.

The problem now becomes one of separating the "backlash" measurements into a true backlash and a gear train windup component. Use is made of the fact that the "backlash" measurement has been completed when the motor and load are moving together. This event occurs when the motor has supplied the power drive's breakaway torque requirement.

A breakaway torque of 1530 ft-lbs (102 amps) is shown in Figure 68 while Figure 74 displays 880 ft-lbs (69 amps). The differential torque of 650 ft-lbs associated with a "backlash" increment of 0.030 mrad results in a shaft windup of 1 mrad/21,700 ft-lbs which represents an extremely stiff geared drive.

This result should be compared to the one presented in the Cost Performance Study Report. The locked rotor resonant frequency measured in previous tests was 109 rad/sec. With a turret inertia of 760 slug-ft^2, the equivalent gear train windup is 1 mrad/9000 ft-lbs. A 2:1 factor is readily apparent between the tests but the previous resonance data is based on an equivalent gear train windup which uses load torque and total shaft deflection, some of which is true backlash. Putting the present data on the same basis results in 1 mrad/10800 ft-lbs (Run 4) and 1 mrad/7850 ft-lbs (Run 2) which averages to 1 mrad/9300 ft-lbs for the two sets of data.

The minimum level of load torque required to move the turret is the torque needed to overcome running friction. A value of 415 ft-lbs (46.5 amps) is obtained from the previous current traces at the time of maximum load velocity. This torque value coupled with the test data indicates a true backlash value of 0.091 mrad which is the minimum motor shaft motion (referred to the load) required to move the load.

b. Elevation Backlash Test

The elevation motor shaft velocity was measured by using the power drive servo's motor speed tachometer. The load velocity was measured by

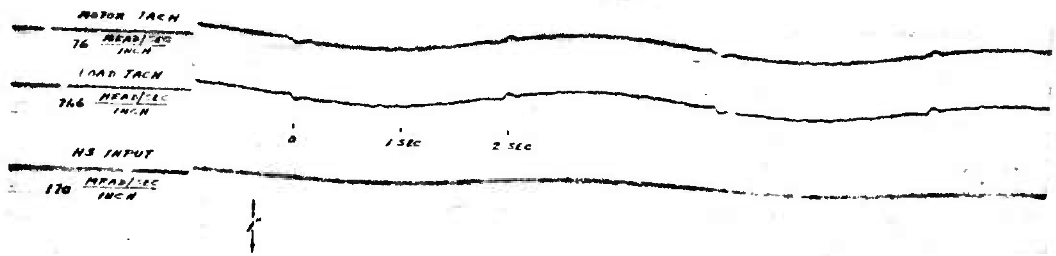


Figure 73 Traverse Backlash Test (Run 2)

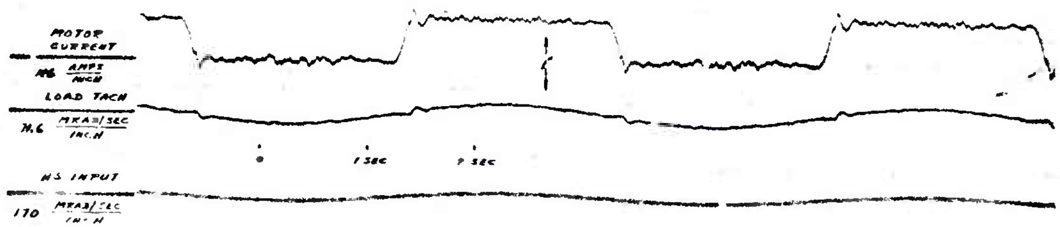


Figure 74 Traverse Backlash Test (Run 2)

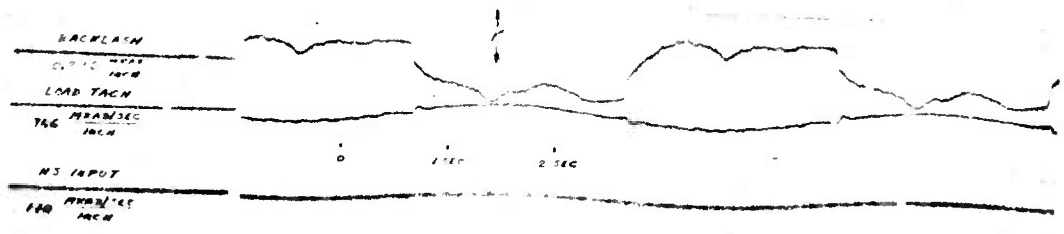


Figure 75 Traverse Backlash Test (Run 2)

using an instrumentation tach located outside the turret as shown in Figure 76. The spring-loaded tach mounting fixture used for the traverse test was mounted on the arm that is bolted to the elevation axis end shield. The rubber O-ring on the tach shaft extension rotates on the 90° roller path segment to provide an approximate gear ratio of 80:1. Figure 77 shows the traverse instrumentation modified for the elevation backlash test.

Before presenting the test results, which are somewhat unusual, one of the design features of the elevation gear train must first be explained. Since the gun's weight is muzzle heavy about the elevation axis, it presents an unbalanced torque of 218 ft-lbs to the elevation power drive. In order to minimize the elevation motor's required torque capability, the unbalanced gun is supported by a counterbalance spring as shown in Figure 78. This spring was designed to present a load speed torque of 218 ft-lbs times the cosine of the gun's elevation angle relative to the hull (COS E).

From Figure 78 it is apparent that the true backlash in the elevation gear train is actually segmented into two distinct parts. A high speed backlash exists in the two gear meashes between the motor shaft and the counterbalance spring shaft. Another lower speed backlash appears in the two gear meshes on the load side of the spring. With no handstation input, the low speed backlash is zero since these two meshes must be in contact for the spring to support the unbalanced gun.

If the gun is now driven upwards, the motor shaft passes through the high speed backlash and presents additive torque to the spring torque with the result that the gun is accelerated upwards. When the gun is commanded downwards, the motor torque decreases the spring torque and the gun is essentially in a controlled free-fall condition. If a downward gun torque greater than 218 COS E ft-lbs is required, the free-fall acceleration is insufficient. The low speed gears must then pass through their backlash in order to come into contact with the lower edge of a geartooth on the sector gear. The motor then provides the additional torque required above the free-fall value.

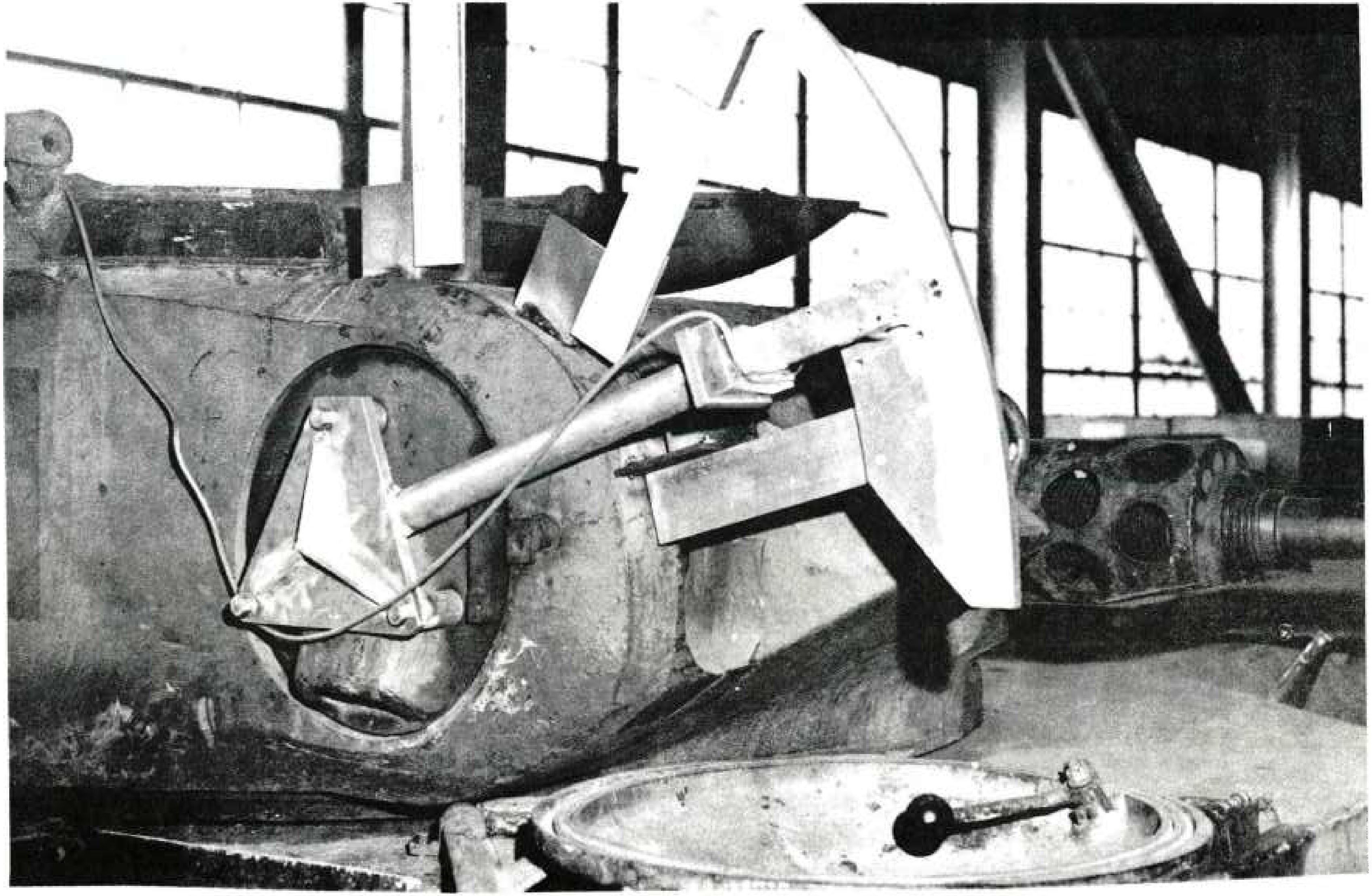
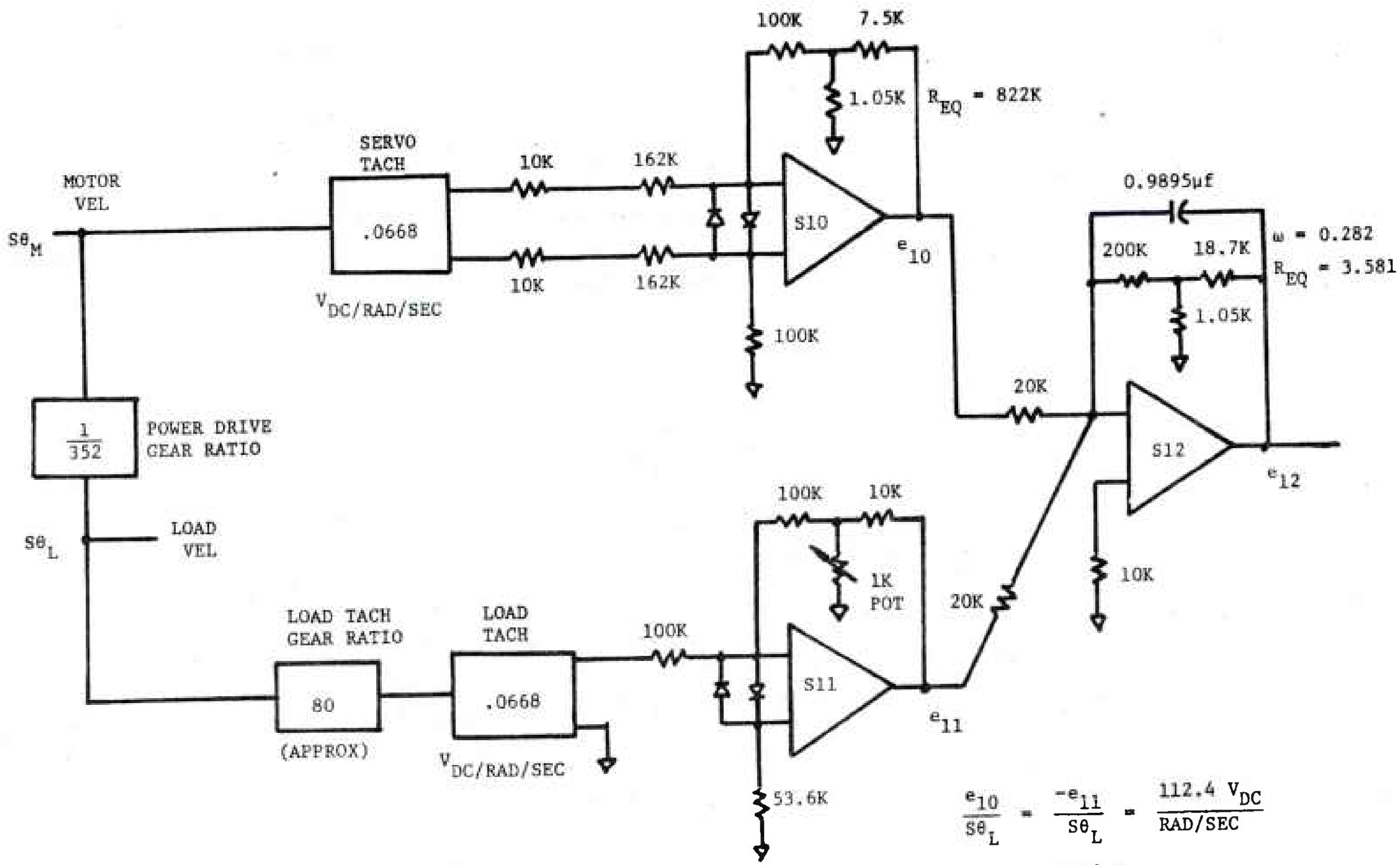


Figure 76 Elevation Load Speed Tach and Roller Path



$$\frac{e_{10}}{S\theta_L} = \frac{-e_{11}}{S\theta_L} = \frac{112.4\ V_{DC}}{\text{RAD/SEC}}$$

$$e_{12} = \frac{5.68\ V_{DC}}{\text{MRAD}}$$

Figure 77 Instrumentation - Elevation Backlash Test

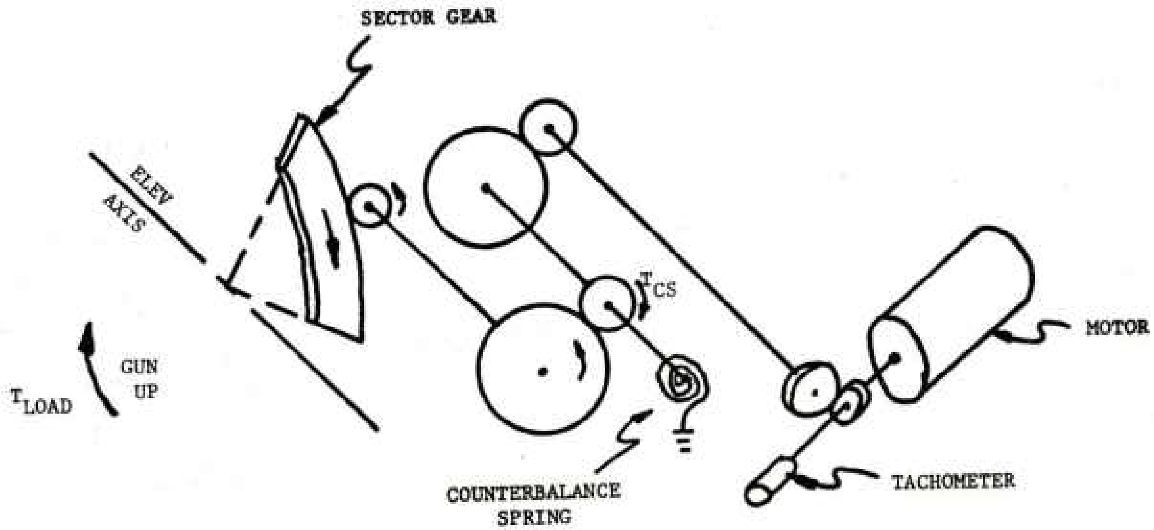


Figure 78 Schematic Diagram - Elevation Gear Train

The previous discussion has shown that one backlash value exists for an upward gun motion while two values can exist for a downward motion. The backlash test was conducted with load torques well below the unbalance torque at all elevation angles. As such, the high speed backlash was being measured.

The results of the test conducted at the largest magnitude of handstation input are shown in Figures 79 through 83. These results are quite unexpected since a backlash of 0.062 mrad exists when the gun barrel moves upwards after zero velocity while 0.226 mrad of backlash appears when the gun barrel starts its downward motion. It is seen from Figures 82 and 83 that the motor tach signal displays a smooth velocity transition when the barrel starts its upward motion while a very ragged signal is present until the load is picked up in the downward direction. Several other tests were then conducted at lower handstation input levels. The results all displayed the same non-symmetrical backlash effect.

It was finally noticed that at gun elevation angles of about 0° to +3° the barrel would rise very noticeably when held and released with the power drive turned off. With the barrel held above the 3° position and released there was no noticeable motion that was readily apparent. This test reveals that the gun now and at the Yakima tests was overequibrated by the counterbalance spring at low elevation angles. The unequal backlash measurements are now accounted for by the unequal motor torques required to lower or raise the barrel. When the barrel is raised the motor must supply little if any torque since overequilibration has already overcome load friction at low elevation angles. When the barrel is to be lowered, the motor must supply the excess equilibration torque to stop the load and then supply the friction torque to lower the load. The original test situation was further complicated by the presence of the load continually drifting upwards. Since the handstation input was being simulated by a function generator, the normal handstation input with its drift correction pot was disconnected. As a result the overequibration torque was continually changing with gun elevation angle.

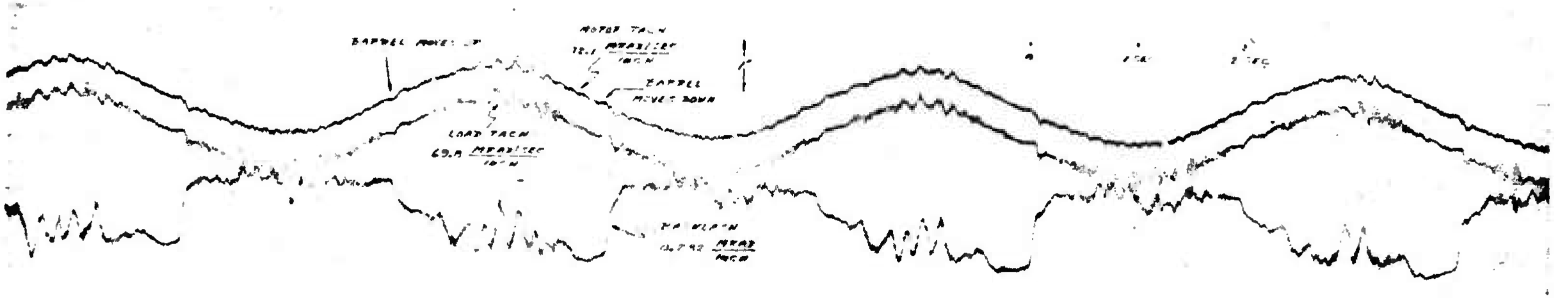


Figure 79 Elevation Backlash Test (Run 3)

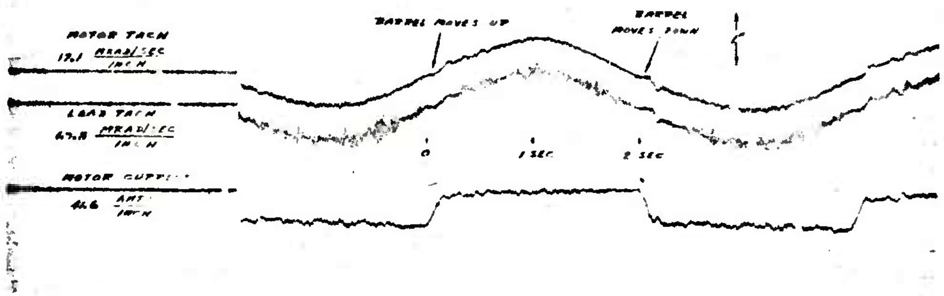


Figure 80 Elevation Backlash Test (Run 3)

Figure 81 Elevation Backlash Test (Run 3)

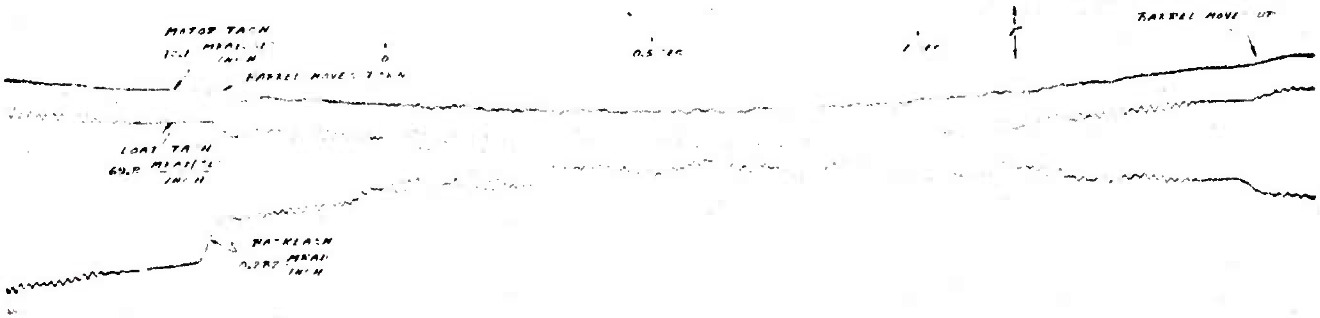


Figure 82 Elevation Backlash Test (Run 3)

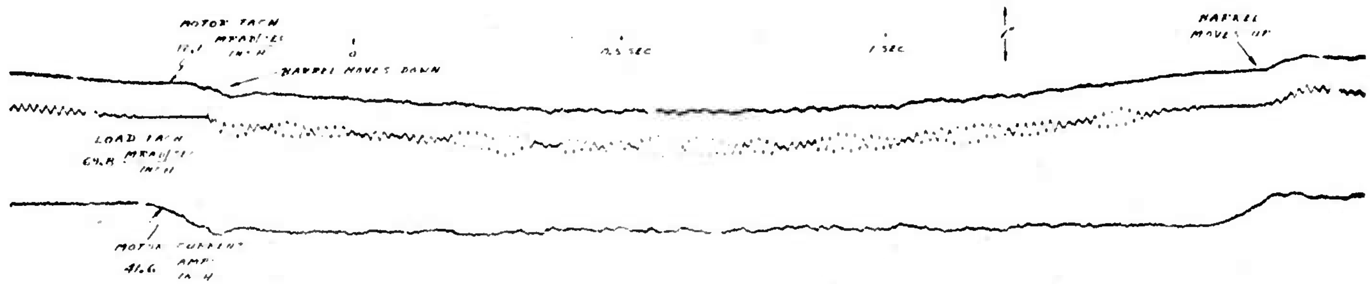


Figure 83 Elevation Backlash Test (Run 3)

Figure 84 Elevation Backlash Test (Run 4)

The backlash test was then redone by turning off the power drive and manually oscillating the gun by pumping the end of the barrel up and down. This test has the effect of a man supplying all necessary load torque and overcoming the tendency of the barrel to rise at low elevation angles. The backlash measurement for this test was made with the same test equipment but now measures the load angle rotation while the motor shaft has stopped. This is still equivalent to measuring the high speed backlash. The results of this test appear in Figure 84 and show a symmetrical backlash measurement of 0.085 mrad. Referring back to Figure 82 it is seen that a backlash of 0.085 mrad (0.30" on recording) occurred at the time that the motor tach signal abruptly changed its initial downward direction. The rest of the Figure 82 backlash measurement is then attributed to gear train windup. While the gear train windup is not available from these tests the data presented in the Cost Performance Study report is still valid since subsequent testing has revealed that the gear train resonant frequencies are unchanged since publication of the report.

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3.0 DATA REDUCTION METHODOLOGY

3.1 Magnetic Tape Data Reduction

In order to validate a mathematical model the model outputs are compared with experimental data from laboratory or field tests, and the model is refined until satisfactory agreement is obtained. Because the data recorded onto magnetic tape was in an analog format and the HITPRO model is digital, the magnetic data was converted to a digital format. Sections 3.1.1 - 3.1.4.2 describe procedures used by Chrysler Defense Engineering for the M60A1E2 Tank magnetic tape data reduction.

3.1.1 Typical Analog Recording

Data was recorded for 95 vehicle runs, spread over ten working days in November of 1971. Each run was of approximately 60 seconds duration and data was recorded for 28 channels of instrumentation. In the first instance, the data was recorded in multiplex form from three telemetry transmitters. The data was subsequently de-multiplexed and re-recorded onto seven tapes, which form the input to this data processing procedure. These final analog tapes carry 14 recording channels, so that the original 28 instrumentation channels were grouped into three data blocks, labeled A, B and C. The instrumentation channels supplied by CDE are included in blocks A and B, and those provided by TECOM are contained in C. The allocation of the original instrumentation channels (as defined in CDE 6231-54) to analog tape channels within the data blocks is given in Figure 85. (Note: Runs #13 and 22A had an exception to this allocation.)

Calibration of the instrumentation channels was performed prior to each run for data blocks A and B, and prior to a day's running for data block C.

Calibration took the form of recording on tape for several seconds with the instrumentation channel inputs at ground ("Lo Cal"), followed by the inputs at some known level ("Hi Cal") and finally connected to the appropriate sensor or monitor point during the course of the vehicle run.

Each data block carries three common channels - voice, IRIG B and the data correlation channel (to provide relative start time between data blocks).

Processing of the raw data is performed in two phases - analog-to-digital conversion (or digitizing) onto an intermediate tape, followed by processing into the final format onto the final tape.

3.1.2 Digitizing

Seven A-D conversion channels are available of which one is always used for the data correlation pulse; leaving six for digitizing "final-output" channels at any one pass of the analog tape. In order to process data blocks A and B two passes are required and for data block C, only one. Thus the three data blocks of the analog tape are transcribed into five on the digitized tape - for the purposes of the processing only. The A-D channel allocation is given in Figure 85.

Digitizing of a particular data block of a particular run on the analog tape is initiated manually during the Lo Cal period of the run and terminated at the end of the run. The digitizing process samples each of the seven A-D channels sequentially every 1 millisecond and writes on tape in the same sequence, every sampled record - in 12 bit binary form.

3.1.3 Final Processing

Processing a particular digitized block involves, in the final instance, transfer of the seven channels onto disc; from where they are extracted channel by channel. During the Lo Cal period of the run a sample of approximately 1 second is taken of each channel and averaged to yield the value of the Lo Cal signal. The program then waits until the Hi Cal step on A-D channel #1 triggers another 1 second sample and average to obtain the Hi Cal value. These Cal values are inserted into a previously prepared record which is written into the final tape as a header record for the run/channel about to be recorded. The averaging process also provided the standard deviations of the signals being sampled and these figures are also included in the header record. The leading edge of the data correlation pulse of A-D channel #7 is used to trigger the processing of the rest of the channel/run data. The digitized raw data is passed through a digital filter (whose characteristics are presented in Figure 86) before being sampled to give the required 10 m sec sample interval (as opposed to the 1 sec sample rate of the A-D). Conversion to BCD representation is then made before writing the final tape. The remaining five A-D channels follow in sequence.

The organization of the final tape is described in Paragraph 4.

(NOTE: In order to be consistent during the Lo Cal, Hi Cal samples, A-D Channel #1 contains analog tape Channel #1, for both passes of

INSTRUMENTATION CHANNEL			CALIBRATION SCALING		ANALOG TAPE	A-D
#	DESCRIPTION	UNITS	Lo Cal	Hi Cal	Data Block/CH #	PASS #/CH #
1	Hull Yaw Rate	DEG/SEC	0.0	-25.0	A1	I 1, II 1
2	Turret Pitch Rate			-25.0	A2	2
3	Turret Roll Rate			-25.0	A3	3
4	Azimuth Gun Rate			- 5.0	A4	4
5	Elevation Gun Rate			- 5.0	A5	5
6	Azimuth Rate Command			- 5.0	A6	6
7	Elev. Rate Command			5.0	A7	II 2
8	Turret/Hull Angle (α)	DEGREES		-45.0	A8	3
9	Gun/Turret Angle (ρ)	"		-25.0	A9	4
10	Azim. Position Error	MILS		12.5	A10	5
11	Elev. Position Error	"		-12.5	A11	6
12	Azimuth Reticle	MILS		25.0	B1	I 1, II 1
13	Elev. Reticle/Trigger	"		-25.0	B2	I 2
14	Turret Vert. Accel.	"g"		3.686	C3	I 3
15	Turret Long. Accel.			3.186	C5	5
16	Turret Trans. Accel.			3.786	C4	4
17	Left Road Wheel	DEGREES		-25.8	C2	2
18	Right Road Wheel	"		25.5	C1	1
19	Drive Sprocket	VOLTS		1.0	C7	6
20	Azim. Control Torque	PSID		-2000.0	B3	I 3
21	Elev. Control Force	PSID		1000.0	B4	4
22	Hyd. Supply Press.	PSIG		2000.0	B5	5
23	Azimuth Servo	INCH		- 0.25	B6	6
24	Elevation Servo	INCH		+ 0.25	B7	II 2
25	Azim. Handle Defln.	DEGREES		-75.0	B8	3
26	Elev. Handle Defln.	DEGREES		-25.0	B9	4
27	Azim. Ref. Demod.	VOLTS		25.0	B10	5
28	Elev. Ref. Demod.	VOLTS		25.0	B11	6
29	Azim. Hull Demod.	VOLTS		25.0	NOT USED	NOT USED
30	Elev. Hull Demod.	VOLTS		25.0	NOT USED	NOT USED
N/A	Data Curr. Pulse	VOLTS	N/A	N/A	A12, B12, C12	7
N/A	Voice	N/A			A13, B13, C13	N/A
N/A	Irig B	N/A			A14, B14, C14	N/A

NOTE: RUN # 13 and 22A (92) had an exception.

INST. CH #	TAPE CH #	A-D CH #
9	B10	II 5
10	B11	II 6
27	A9	II 4
BLANK	A10	II 5

Figure 85 Calibration and Channel Cross-Reference

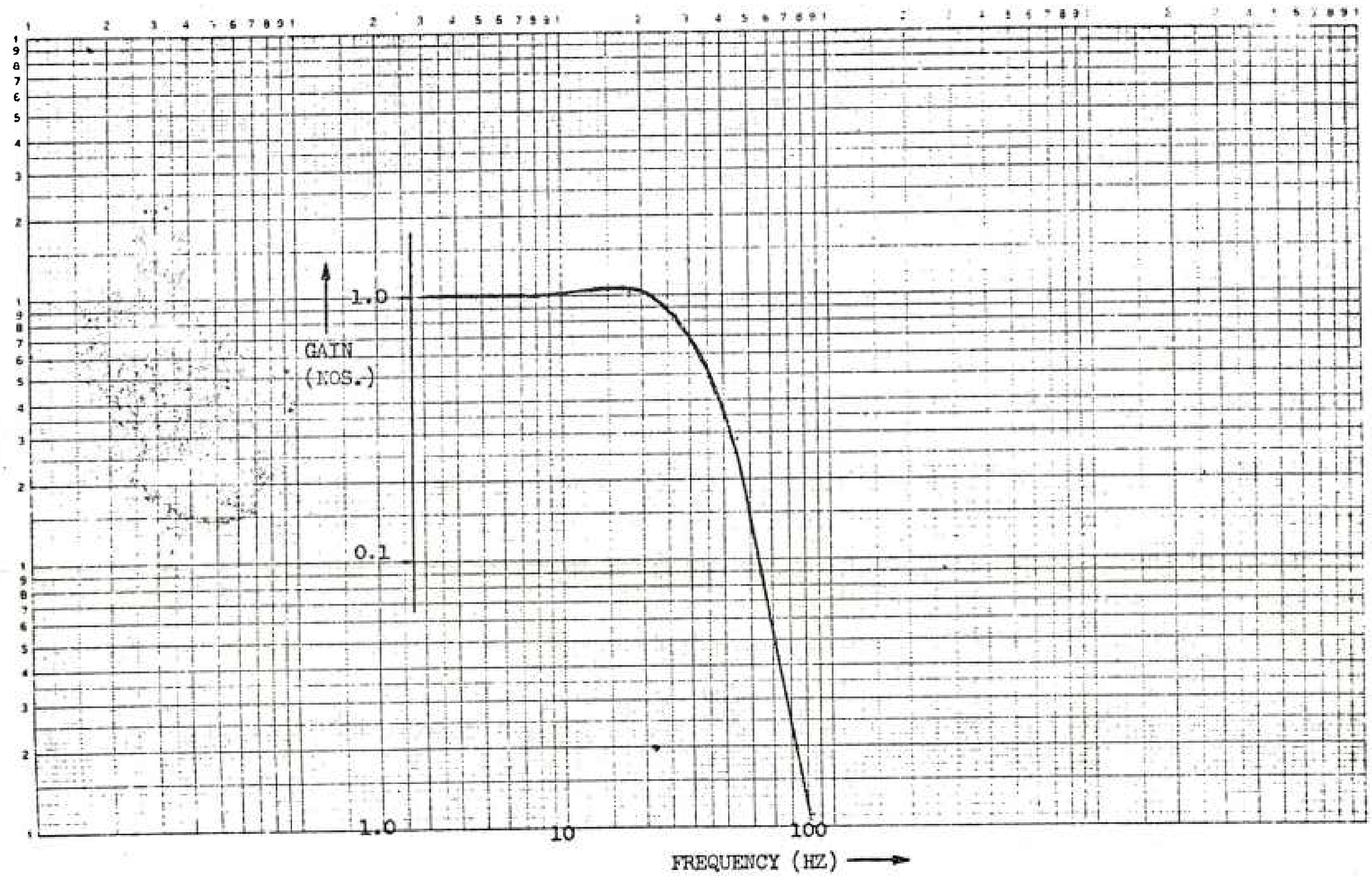

Figure 86 Digital Filter Response

data blocks A and B. Thus tape Channel #1 for both A and B is repeated and the final tapes will include 30 blocks per run - 28 channels plus 2 repeats.)

3.1.4 Organization of the Final Tape

Any one RUN of the 95 HITPRO runs will be presented as 30 BLOCKS of data records. (One block for each instrumentation channel, plus two repeats.) Each block will be made up of 190 RECORDS, the first of which will be a HEADER RECORD and the remaining 189 DATA RECORDS. The format and contents of these records are given in Paragraphs 4.1 and 4.2.

The distribution of the data blocks and run numbers across the seven analog tapes has made it impractical to logically sequence runs and channels on the final digital tapes. Whereas every attempt will be made to get all channels for a particular run together, there can be no guarantees of this. However, all 190 records of any digital block will occur in one final tape and not be split between two tapes.

An end-of-file marker will not be placed after each block, but will be placed after the processed blocks on each tape.

3.1.4.1 The Header Record

The first record in any block of data records is a header record which is intended to identify the block and provide the calibration information. Its general form and a couple of samples are given in Figure 87. The record will comprise 128 BCD characters which may be read using a format such as

FORMAT (A88, 5I8).

The five integer elements contain the digitized values of the Lo Cal and Hi Cal, the standard deviations of the samples from which these values were averaged, and a sequence number, respectively.

The information contained in the character format of the record to identify the particular run and channel is given in Table 2.

3.1.4.2 The Data Records

Each data record is made up of 32 data elements, each of which represents the digitized value of the channel every 1/100th second. Each data element is specified as 4 BCD integers and should be read using:

FORMAT (32I4)

TABLE 2 DATA CONTAINED ON HEADER RECORD

BEGINNING AT CHAR. #	FIELD LENGTH	DESCRIPTION	RANGE OF VALUES
6	A2	HITPRO run number	1 to 90, 91, 92, 95, 96, 98 +
12	A2	Instrumentation Channel No.	1 to 28 *
18	A1	Data block on analog tape	A, B or C
20	A6	Date of HITPRO run (11 x 71)	x = 5, 8, 9, 10, 17, 18, 22, 23, 24
35	A2	Analog tape Channel No.	1 to 11 *
41	A2	Analog reel number	2A, 3, 4, 5, 6, 7
53	A5	Lo Cal scaling	0.0
59	A6	Hi Cal scaling	Various *
65	A9	Scaling units	Various *
79	A2	A-D Channel Number	1 — 6 *
81	A6	Hi Cal Scaling (Repeat)	-
87	A2	Blank	-
89	I8	Lo Cal Value	Between 0000 and 9999
97	I8	Hi Cal Value	Between 0000 and 9999
105	I8	Lo Cal Standard Dev. Value	Between 0000 and 9999
113	I8	Hi Cal Standard Dev. Value	Between 0000 and 9999
121	I8	Sequence #	Not Significant

* See either CDE 6231-54 and/or Figure 85 this document.

\+ For the convenience of the header records the following run numbers have been re-allocated. The original run number is from WECOM TEST PLAN TPR #SWERR-T-125-AC and as recorded by voice on the analog tapes. The processing number is as included in the header records on the final tape.

ORIGINAL #	PROCESS #
21	21
21A	91
22 PRIME	22
22A	92
58 PRIME	98
75 PRIME	95
76 PRIME	96

3.2 THE HITPRO M1CV-65 DATA BASE

3.2.1 History

The data base consists of data digitized by Picatinny Arsenal from analog data tapes generated at Yakima, Washington. The digitized runs were selected by Capt. John Mandzy.

The tapes generated by Picatinny are in binary form which necessitates a conversion program. This program was developed by Dr. James Hurt, Mr. Michael Minnich, and Mr. Allen Sulivan. This program will convert a 7 track binary tape to a 9 track EBCDIC tape.

3.2.2 Procedure

A program exists to create a single data set. Associated with this program is a procedure (see Listing 1) which allows the user to specify which tapes to use, which data sets to read, and which to create.

The basic setup for a single data set is

```
// JOB                                              1
// EXEC MP3C1BDC,CORE=72K,                          2
// TA=TMØØ97,N=95,N1=21,N2=22,NAME=RN81C2           3
// INPUT DD*                                        4
          -1.       1.
 2000                                               5
```

where TA = The volume serial number of the tape on which the new data set is to reside.

N = The number of the data set on tape TA used in the LABEL = parameter of the proc.

N1 = The number of the header data set of the binary data (see Figure C-1.)

N2 = The number of the binary data set on the master tape.

NAME = The name (DSN) which will be associated with the new data set.

This procedure applies only to data contained on tapes TMØ336 and TMØ337.

The data needed for proper execution of the program is the <u>REAL</u> (actual) High and Low values for a data channel i.e. $\pm$ for and acceleration channel, and the number of points (currently 2ØØØ and never changed). The formats for these data items are 6F10.0 and I5.

After running this procedure, the sata set(s) will exist on a specified TAPE. The format of the tape is as follows:

(1) First record is a header. This record is 70 characters long and

```
MEMBER NAME  MP3C1BDC
//CONVERT PROC TA=TM0096,N=1,TA1=TM0336,TA2=TM0336,N1=1,NAME=RN80C20,
//     N2=2,CORE=200K
//STEP1 EXEC PGM=MP3C1BDC,REGION=&CORE
//STEPLIB DD DSN=LOAD.MPROD,DISP=SHR
//FT05F001 DD DDNAME=INPUT
//FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=13300)
//FT10F001 DD UNIT=TAPE9,VOL=SER=&TA,LABEL=(&N,SL),DISP=(NEW,KEEP),
// DCB=(RECFM=FB,LRECL=70,BLKSIZE=7000),DSNAME=&NAME
//FT01F001 DD UNIT=TAPE7,VOL=SER=&TA1,LABEL=(&N1,NL),DISP=SHR,
//     DCB=(RECFM=U,BLKSIZE=80,TRTCH=ET)
//FT01F002 DD UNIT=TAPE7,VOL=SER=&TA2,LABEL=(&N2,NL),DISP=SHR,
//    DCB=(RECFM=U,BLKSIZE=2000,DEN=1)
```

TA	is	Volume serial number for output tape.	Default is TMØØ96
TA1	is	Volume serial number for input tape.	Default is TMØ336
TA2	is	Volume serial number for input tape.	Default is TMØ336
CORE	is	Region size needed to execute the program.	Default is 200K
N	is	The output data set number.	Default is 1
N1	is	The data set number of the header data set	Default is 1
N2	is	The data set number of the binary data set (In all cases N2 = N1 + 1)	Default is 2
NAME	is	The data set name of the output data set.	Default is RN8ØC2Ø

Listing 1 Listing, Computer Printout

contains the analog high and low values, and the true high and low values. The first 38 characters are title information (Run number and channel number)

(2) The rest of the records are 70 bytes in length, with a 10F7.3 format. These may be read in a 10F7.0 format. The tape type is 1600 BPI, 9 Track, Standard Label, DCB Parameters are RECFM = FB, LRECL = 70, BLKSIZE = 7ØØØ. The input tape is 7TRK, 556BPI, RECFM = U, BLKSIZE = 2ØØØ.

3.3 Investigation of Digital Filtering Techniques for the Analysis of Experimental Data

Technical Report DDC number AD A016928, by Lanny D. Wells, describes generalized techniques for isolating a signal from background noise, a means of removing low frequency drift from a signal, and a means of selectively reversing previous filtering. These techniques were valuable in the refinement and validation of HITPRO, and are discussed in that report.

3.4 Stabilization Performance

Split image film data recording the gunner's sight line was used as the basis of comparing the stabilization performance of the all electric gun drives and the electro hydraulic gun drives as mechanized in two M60A1E2 Tanks. A simple, inexpensive method of film reading was developed for this effort and compared with previous measurements made using a Vanguard Motion Analyzer.

```
                HITPRO         INST.            DATA       RUN                                  TAPE
                 RUN #         CH #             BLOC       DATE                                 CH #
ORMAT   R U N b b X X b C H b X X b D B b X b X X X X X X b T A P E b C H b X X b R L b
XAMPLE  R U N     1 9   C H     1   D B   A   1 1 0 5 7 1   T A P E   C H     1   R L
        1

        TAPE                             SCALING                    PHYSICAL                 A-D
        REEL #                    Lo . CAL         Hi . CAL           UNITS                  CH #
ORMAT   X X b L O / H I b C A L b b 0 . 0 / X X X X X X b X X X X X X X X A D b C H X X
XAMPLE  2 A   L O / H I   C A L     0 . 0 /   - 2 5 . 0   D E G / S E C   A D   C H   1
        41

        Hi CAL               Lo CAL             Hi CAL             Lo CAL             Hi CAL
        SCALE                VALUE              VALUE              STD . DEV          STD . DEV
ORMAT   X X X X X X b b X X X X X X X X X X X X X X X X X X X X X X X X X X X X X X X X
XAMPLE   - 2 5 . 0                 4 3 9 8            1 1 7 8                3 8                . 3 6
        81

            SEQ . #
        X X X X X X X X
        121          128
```

Figure 87 Header Record Format

4.0 HITPRO VALIDATION

4.1 General Electric Letter

This letter typifies the care taken in designing the critical data collections in order to achieve validation.

SEE ATTACHED.

4.1 General Electric Letter

GENERAL ELECTRIC COMPANY

ELECTRONIC SYSTEMS DIVISION

100 PLASTICS AVE., PITTSFIELD, MASS. 01201 . . . DIAL COMM 8*233-...., (413) 443-3561

ORDNANCE SYSTEMS

September 28, 1970

Commanding General
U. S. Army Weapons Command
Research & Engineering Directorate
Rock Island Arsenal
Rock Island, Illinois 61201

Attention: Mr. S. Birley, AMSWE-REV/AC

Subject: M60A1/E2 Testing for HITPRO Validation

Dear Mr. Birley:

This letter is in response to a number of questions from you and Harold Liberman regarding the instrumentation for the subject tests, and particularly regarding the number of shots required. As I indicated to you, I have discussed the testing program with some of our statisticians. The general observations from these discussions were:

1. The firing tests provide a means for validating the overall HITPRO program, which includes models of several subsystems. Validation is thus greatly enhanced by the use of instrumentation of individual subsystem inputs and outputs, in addition to the overall firing results.

2. The quality of information obtained from repeated tests (shots) tends to vary approximately as the square root of n, the number of shots (See Figures 1 and 2). That is, if the number of shots associated with a particular situation is increased from a few (less than five) to 15 or 20, there is a substantial improvement in the quality of information obtained. However, the attaining of a further, equivalent improvement in information requires a much larger increase in the number of shots, to 50 or more. Thus, there is nothing particularly significant in 20 shots, - rather something in the range of 15-25 appears to be beyond the "knee of the curve" and higher numbers run increasingly into the "law of diminishing returns"

These observations, perhaps in less definite form, have been realized for a long time and have been incorporated in the test plan. That is, instrumentation has been installed to measure the outputs of various major subsystems so that the various parts of the HITPRO model can be validated:

(1) The first major block of quantities modeled in HITPRO is the

motion generation, using subroutines MOTION, BUMPS and SUSPEN. These generate three components of linear acceleration, angular acceleration, angular velocity and angular position. These are basically generated in hull coordinates but resolved to turret coordinates for use in DRIVE, COSIGH and other portions of the program.

The test instrumentation measures the linear accelerations, the angular velocities and two components of angle basically in turret coordinates. Traverse angle is available for resolution of these quantities to hull coordinates if desired.

Two of the three components of angular velocity are measured by tachometer, rather than rate gyro, because this instrumentation is already available with good signal level. Use of a tachometer, rather than a gyro, requires an inertially stabilized reference which is the gun axis in these tests. The gun will normally remain stabilized to an accuracy of about 1 mr. Since the vehicle motions are typically of the order of 100 mr, the gun reference provides a basis for tach measurement of vehicle rates accurate to about 1%. Of course, the transient motions of the gun (errors in stabilization) are being continually monitored by gun gyros and camera so that the tach measurements can be corrected for gun motion, if desired. This will not be worthwhile, as the basic errors of tach and recording will be at best in the 2-4% range.

We are anticipating agreement between model and vehicle motions in the qualitative "signature" and in the large magnitude values to about 10-20%. I think our instrumentation is adequate to perform this degree of validation.

To satisfy my own curiosity, I would have liked to instrument angular acceleration and wheel positions also. However, as it is, we anticipate considerable effort to keep all the present channels operative, zeroed, calibrated, etc.

(ii) The next subroutine encountered in HITPRO is COSIGH, Computer and Sight. During test, the manual inputs of range and wind are recorded, and the traverse angular rate during lead angle reset can be determined from both gunner hand station input and gun gyro output. Solutions for lead angle above, total deflection angle and superelevation are recorded continuously with a resolution of 0.05 to 0.1 mr. This, of course, is somewhat better than the accuracy of the XM19 solutions.

(iii) The third major subsystem modeled in HITPRO is the gun servo drives, subroutine DRIVE.

The inputs of sight reticle position and gunner hand signals are continuously recorded as are the vehicle motion disturbances. The stability of the gun in elevation and traverse is measured by the gun mounted gyros. Of course, the instantaneous pointing of the gun, including stability, is determined with great precision (0.05-0.1 mr) from the boresight camera.

Again, it is anticipated that the error "signature" of the model, that is, the response of the gun to disturbances, will match the test and that the magnitudes at large values will check to 10-20%.

(iv) Subroutine GUNNER

The visual error input to the Gunner Transfer function is obtained either from the split image camera on the periscope, or a combination of boresight camera and reticle position. The output of the transfer function is the hand inputs of command rate to the gun servos, which are continuously recorded.

The Gunner response will be the most difficult of all the HITPRO "subsystems" to validate. We know from previous measurements that gunners will respond differently on different occasions and also different than other gunners. Thus, there will be no typical response "signature" that can be validated. However, there is some experience to indicate that overall pointing accuracy and time to achieve that accuracy will be somewhere near the same for gunners of comparable experience. Thus, it will be only the performance results of the gunner that will be validated.

Furthermore, since the gunner may exercise considerable adaptability which would be impossible to simulate, it will be necessary to specify quite precisely the firing procedure that the gunner is to use in the test, - approximate time spacing, range and lead set methods, aiming tolerance for firing, etc.

(v) Subroutine TRAJEC

This subroutine contains the shell ballistics and requires some actual firing for validation. The shell has dispersion so that a number of shots will be required to determine the center and dispersion of the shot pattern. Figure 1 shows the accuracy of the center of the pattern relative to the expected dispersion as a function of the number of shots. The three curves are for different values of confidence. Figure 2 provides data relative to validation of the expected dispersion magnitude. Strictly, Figure 2 presents rejection limits for the expected dispersion.

The above paragraphs have indicated briefly the instrumentation involved in validating each portion of HITPRO and the degree of validation, or agreement between simulation and test, anticipated. Of course, there is also a need for an overall validation of HITPRO, with no recourse to intermediate measurements of gun servo error, gunner response, etc. This would involve simply a measurement of shell impact errors for different situations (range, vehicle and target speeds, maneuvers, etc.). The curves of Figures 1 and 2 still apply, but the expected standard deviation, σ, now is a combination of shell, drive, computer and gunner induced dispersions.

Very truly yours,

P G Cushman

P. G. Cushman
Adv. Market Development Engineer
Advance Market Development
Room 1150 - Extension 2786

/jh

attachment

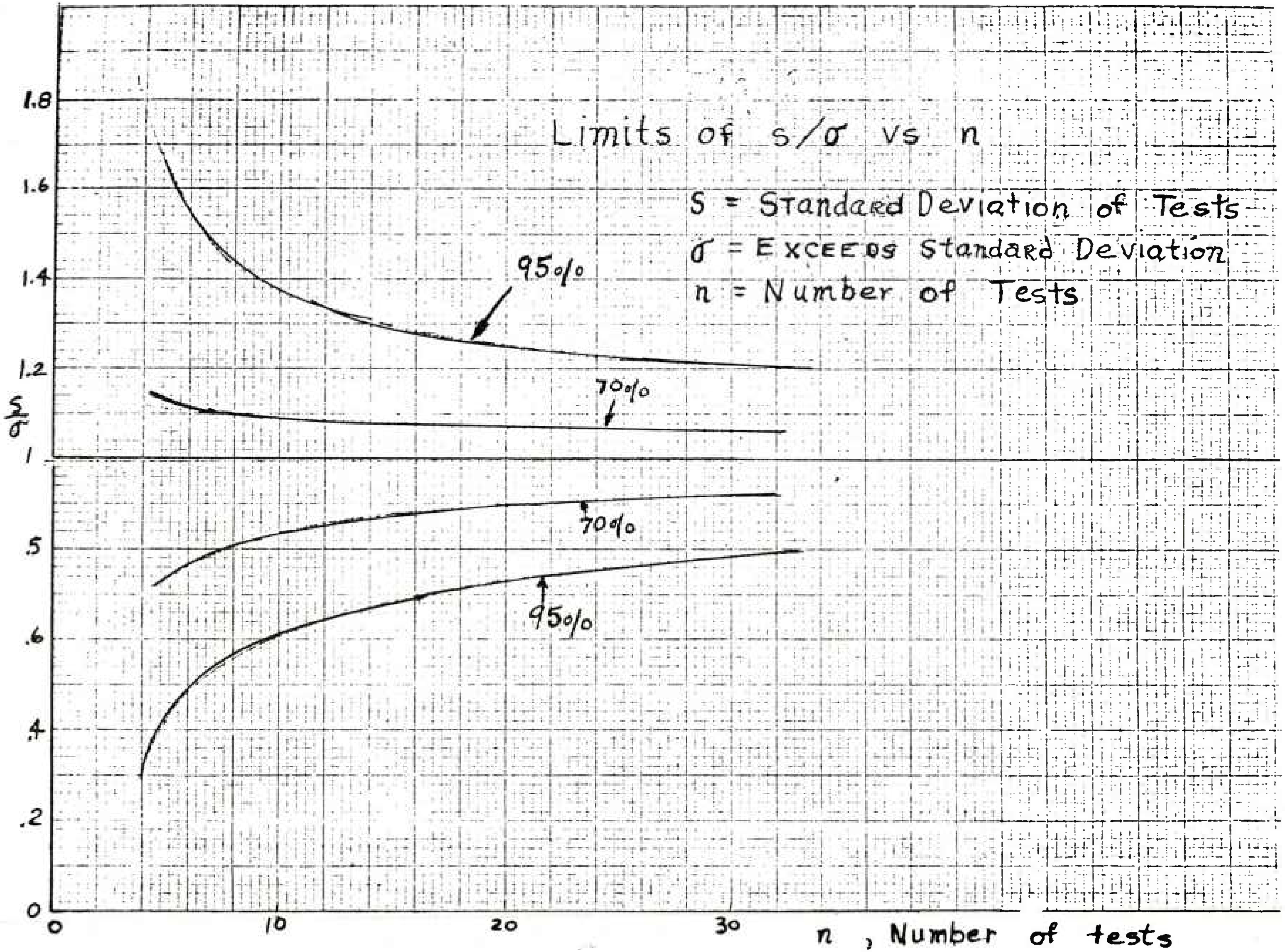

Figure 1 to G.E. Letter, Dated 28 Sep 1970

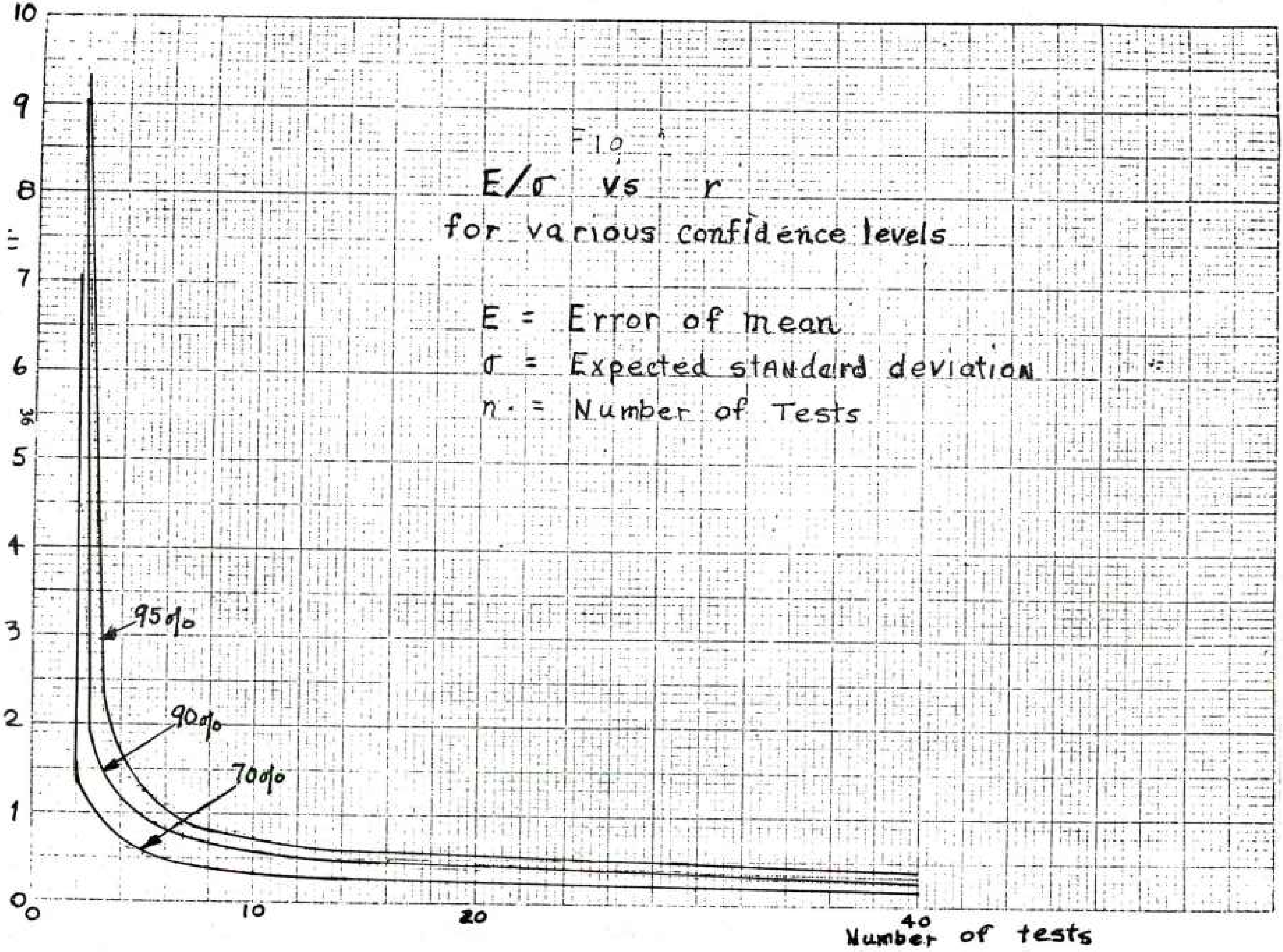

Figure 2 to G.E. Letter, Dated 28 Sep 1970

4.2 Procedure

Three methods of comparison have been applied to the test data and the computer predictions:

a. Visual comparison of overlays of time traces.

b. Visual comparison of frequency spectra, and

c. Correlation analysis

4.2.1 Comparison of Curves

For validation of the HITPRO model curves of various model parameters and corresponding channels of recorded data were compared. Both time traces and power spectra were compared. In some cases, graphs of the logarithms of the Power Spectra were investigated. The time traces from the HITPRO model were direct output from the model, while the time traces of the experimental tests were the result of the digitalization of analog tape recordings. The spectral plots were the output of a computer program using techniques developed in the report "Basic Elements of Power Spectral Analysis" by Davis D. Sentman. Because of electrical noise in the recording equipment and because the spectral plots indicated unrealistic power of certain high frequencies, some of the experimental results were digitally filtered. The digital filter used was a relatively simple and efficient one whose main tool was the use of the Fast Fourier Transform.

Initially, using the APG test course layouts, the HITPRO output did not yield favorable comparison between experimental data and model predictions. A check of time traces of the vertical velocity of the left and right front wheels gave evidence that the layout bump locations were not entirely accurate. Agreement became better once the correct bump locations were used.

Another problem area in the comparison of HITPRO with experiment is vehicle velocity. The driver is not capable of maintaining a precise speed when addressing the course. Whereas the computer model maintains the speed it is given. Therefore minor time variances in events must also be overlooked. It should be said, for emphasis, that obtaining agreement between HITPRO and experiment required modification to the data only and not the model. And when the data was altered, it was done so only after being proven that it was in obvious error.[3]

[3]Technical Report "Investigation of Digital Filtering Techniques for the Analysis of Experimental Data, DDC Number AD A016928

A sampling of validation results are shown in Figures 88 and 89. Figure 89 shows a representative motion parameter, pitch angular rate, as predicted by HITPRO and measured from the M60A1E2 Tank with all electric gun drives running at approximately 7 mph over the Aberdeen Bump Course. Note the close correlation of the large amplitude motions, Figure 88 shows a spectral plot of turret pitch velocity relative to space.

4.2.2 Correlation Analysis

In an effort to quantitate the degree of agreement between the mathematical model and the physical system, the correlation factor, C(o) was calculated, C(o) is defined as:

$$C(0)= \frac{\overline{(x(t)-\overline{x(t)})\ (y(t)-\overline{y(t)})}}{\left(\overline{(x(t)-\overline{x(t)})^2}\ \ \overline{(y(t)-\overline{y(t)})^2}\ \right)^{1/2}}$$

where the bar denotes a time average and where x(t) is the prediction of the simulation and y(t) is the experimentally measured quantity. When x(t) and y(t) are identical, the correlation factor is 1, when they are independent it is 0. In between these extremes, the relationship between the agreement of x and y and the correlation factor is less well defined, although the higher the correlation, the better the agreement.

The correlation factors computed for several channels on a run over the bump course at 7 mph are shown in Table 3. Although these correlation factors do not provide an objective criterion for the agreement between the model and the physical system, they do provide a future objective relative criterion for choosing between two models of the same physical system.

4.3 Conclusions

Because of the good agreement between overlays of time traces and frequency spectra of the experiment and the model under rather severe test conditions, we believe that HITPRO is a good model of the M60A1E2 and MICV-65 testbeds. In the main, however, these low values of the correlation factor indicate that correlation analysis is a more sensitive tool in detecting imperfections in the model than visual comparisons and correlation analysis will be useful in evaluating improvements to the model.

TABLE 3 CORRELATION VALUES FOR RUNS AT 7 MPH OVER THE ABERDEEN PROVING GROUND BUMP COURSE

	Channel	C(o)
4	Gun turret relation angular velocity	.72
9	Turret vertical acceleration	.71
11	Turret fore and aft acceleration	.61
12	Turret side to side acceleration	.30

Correlation values for runs at 7 mph over the Aberdeen Proving Ground Bump Course by the M60A1E2 Tank with all electric gun drives.

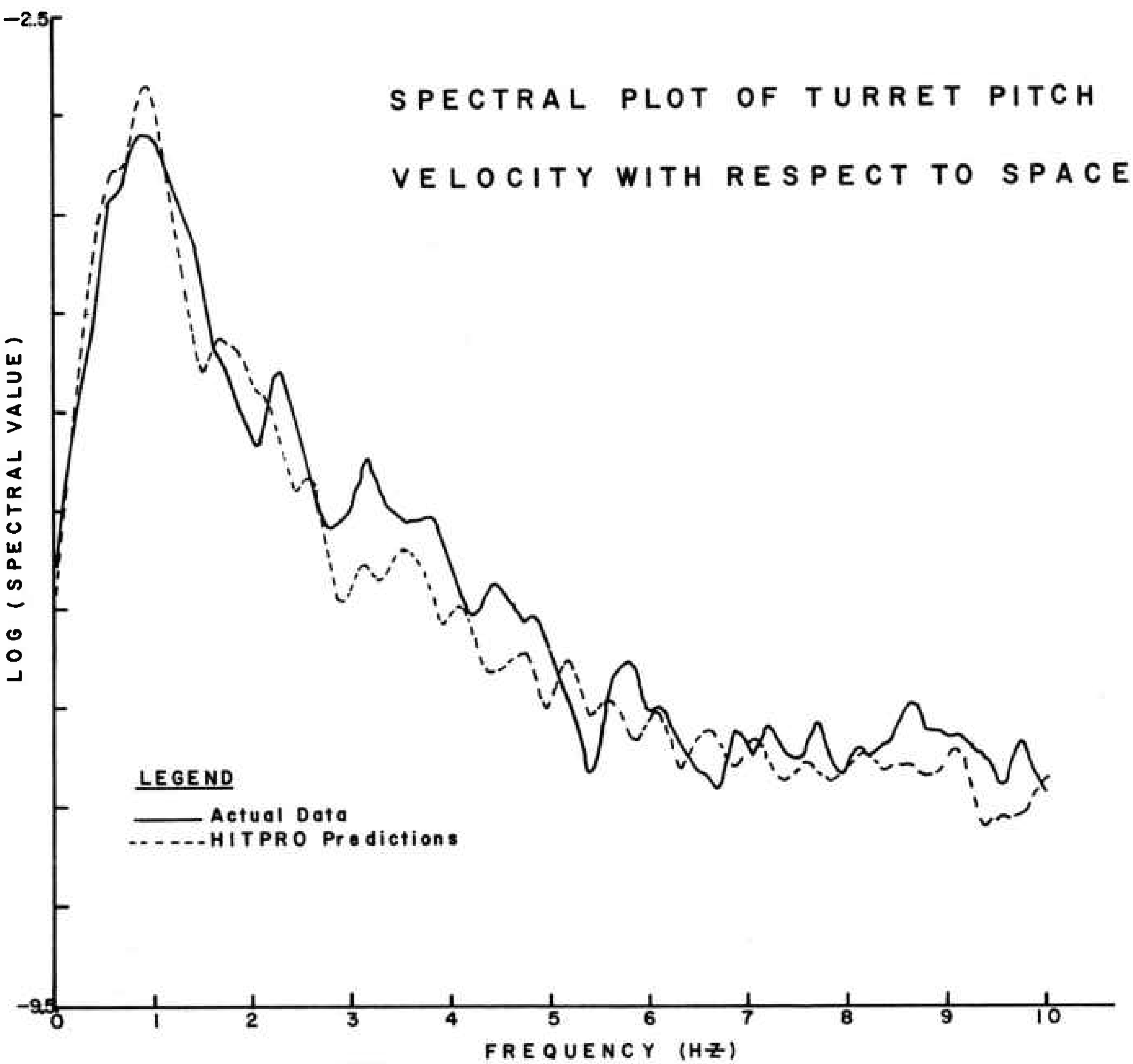

Figure 88 Comparison Between HITPRO Prediction and Test Data

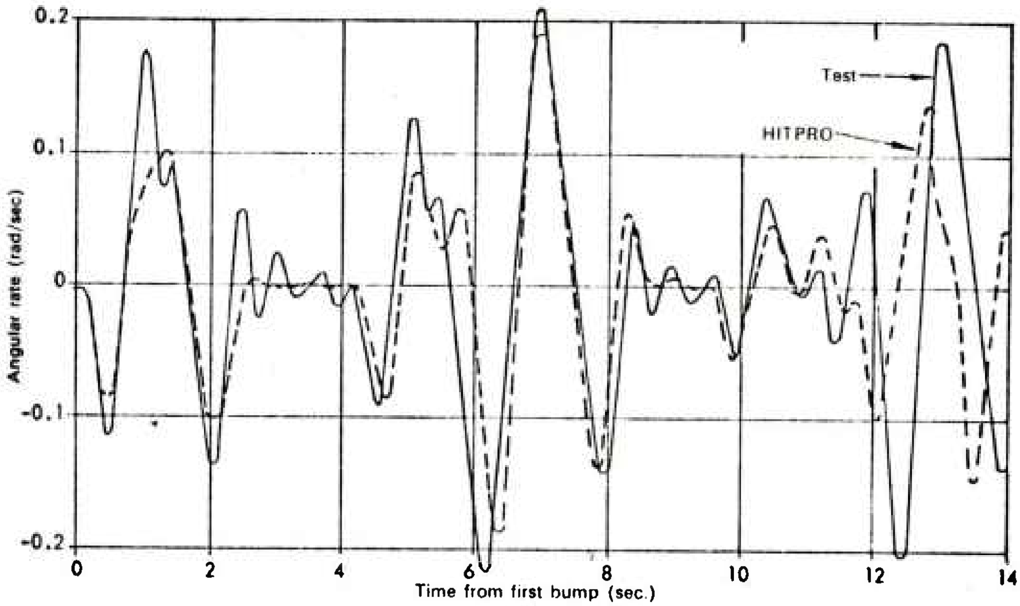

Figure 89 Pitch Angular Rate, Simulated and Measured, on APG Bump Course at 7 mph

5.0 STABILIZATION SYSTEM PERFORMANCE

5.1 Approach

5.1.1 General

The comparison of tests performed at different times and different places is exceedingly difficult. Unless great care is taken in the design and performance of these tests, the identification of the subsystems responsible for the degradation of overall system performance is not possible.

The use of mathematical simulation whose predictions have been verified by limited hardware tests overcomes these obstacles, i.e., test conditions and terrain can be standardized and human variations eliminated.

5.1.2 Rationale for Percent Time on Target as a Measure of Stabilization System Performance

The percent of the time that the gunner's reticle remains on the target for a specified target, range, and test condition is a measure of the combined performance of the gunner's ability to track and the stabilization system. For a square or circular target, the assumption that the combined error is an ergodic random process with a Gaussian distribution enables the dispersion of the distribution to be estimated from the percent time on target. The advantage of specifying time on target as a measure of performance is the ease of measurement.

Besides the interaction with the gunner in the tracking mode discussed above, the stabilization system and the gunner interact in gun laying. The stabilization system must not degrade the gunner's ability to lay on stationary or moving targets while the vehicle is stationary.

It is possible to measure directly the error contribution due to the stabilization system. The gun pointing error occurring in a run over rough terrain against a stationary target with the gunner's hands off is due to stabilization system error. Some additional instrumentation or detailed analysis of gun sight film are required to quantify this error. Interactions between subsystems should not be ignored, however.

For systems employing a fire control computer, the stabilization system, the gunner, and the fire control system also interact in the computation of the lead angle. Present systems utilize either a turret mounted gyro or the gunner's rate commands to sample target rate. Both of these methods are sensitive to stabilization error.

To judge the performance of complex systems such as tanks, MICV's and helicopters with stabilized weapons and/or stabilized sights, it is important that both overall system performance, i.e., hit probability or time on target and subsystem performance be measured, i.e., dispersion in lead, range, gun pointing, etc. be measured. Such individual subsystem performance measurements require extensive instrumentation and carefully-controlled test conditions, however, the resulting data is also useful for identifying subsystems that limit overall system performance.

5.2 Gun Pointing Accuracy

An accuracy analysis was performed to compare the relative performance of the all-electric and the electro-hydraulic stabilization systems as mechanized in the non-standard M60A2 tanks. Gunner's sight film and the validated HITPRO model were used to generate the gun pointing errors, in terms of standard deviation, as shown in Table 4. (Note the close agreement between the predicted values and the actual test values for the electro-hydraulic system.)

TABLE 4 STANDARD DEVIATION OF POINTING ERRORS (MILLIRADIANS) FOR NON-STANDARD M60A2 TANK

Scenario	All Electric Stabilized	Electro-hydraulic Stabilized
Hitpro Simulation Results:		
Hands-off/bump/8mph/HITPRO non-firing		
Elevation	0.10**	0.48 (0.46)*
Traverse	0.28	0.41 (0.53)*
		* From APG test data, all electric "hands off" runs were not made.
Gunner's Sight Film Results:		
Bump/7mph/stationary target/APG firings		
Elevation	0.51	
Traverse	0.55	
Bump/8mph/stationary target/APG firings		
Elevation		0.68
Traverse		0.67

**HITPRO results are somewhat optimistic in that phase shift in the hull rate gyro and gear box flexibility are not included. The error introduced by the approximations are small compared to errors introduced by other system elements (e.g., gunner) in normal vehicle operation.

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6.0 IMPROVED FIRE CONTROL

6.1 Recap of Investigation

During testing of the M60A2 tank with the all-electric stabilization system at APG in Nov 1970, it became apparent that even though the gunner was able to track the target satisfactorily, the lead angle computation technique was inadequate to effectively fire on the move.

General Electric had previously conducted a study of possible improvements to the fire control system. With guidance from a committee consisting of representatives from WECOM, AMSAA, and Frankford Arsenal some of these improvements were selected and simulated by G.E. in the HITPRO model. The most promising fire control modifications were subsequently mechanized in the M60A2 all-electric test bed.

The modifications mechanized include:

a. An improved weighting function for the target rate averaging network.

b. Estimation of the target rate based on the gunner's traverse hand station input rather than the present gyro.

c. Continuous lead sampling.

d. Rate-aided tracking, i.e., automatic correction for own vehicle velocity normal to the LOS to the target in both the gun pointing and own vehicle contribution to lead.

e. Correction for own vehicle cross wind generated by the vehicle velocity normal to the LOS to the target.

f. Dynamic correction for gun trunnion cant. This correction affects the superelevation as well as the lead angle.

Improvement A. corrected the averaging network to the desired weighting function shown in Figure 93 (section 6.2). This correction was implemented in the fire control computer of the standard M60A2.

Improvement B. was implemented and tested at APG in November 1971. In our testing, hand station sampling was compared with gyro sampling. The results for about 30 firings for each case on the bump course against a moving target indicate that the standard deviation of the lead angle fluctuation was reduced from 2.6 mr to 1.1 mr for the hand station sampling. This improvement has been incorporated into the M60A3 tank.

Improvement C. reduces the time delay between beginning of track and firing, important in maneuvering such as on the Zig-Zag course where relative target rate changes rapidly.

Improvement D. reduces tracking effort required of the gunner and speeds the response of lead to own vehicle maneuvering since own velocity component to lead is not averaged, thus providing a capability of firing while maneuvering.

Improvement E. corrects for own vehicle cross wind which is a significant factor (not necessary if vehicle has wind sensor).

Improvement F., like Improvement E., is necessary for a slow round such as the 409. The present system has a cant correction for stationary firing, but it is switched out for moving firing because of its slow response. The need for correction arises because the superelevation and lead angles are inserted about the gun trunnion axis and the turret axis, respectively, instead of a horizontal and vertical axis as required (as shown in Figure 90).

The mechanization of these improvements includes the provision for most to be tested independently. The improvements were tested at Pittsfield, Mass, and an advanced tank fire control orientation was presented on 26 Apr 1972 at Rock Island Arsenal. A special test was run to check the performance of rate-aided tracking. In this test, the tank was run over a Zig-Zag course and a stationary target was chosen which was obscured over a large part of the course (see Figure 91). The course was run with continuous lead, and with and without rate-aided tracking. This test demonstrated that the mechanization of the rate aiding works well.

Some conclusion can be based on results of HITPRO math modeling, and these test results, it is concluded that:

a. The modifications are relatively easily made.

b. The performance of the system is substantially as predicted by the HITPRO math model.

c. These improvements are worthy of future consideration in tank fire control systems.

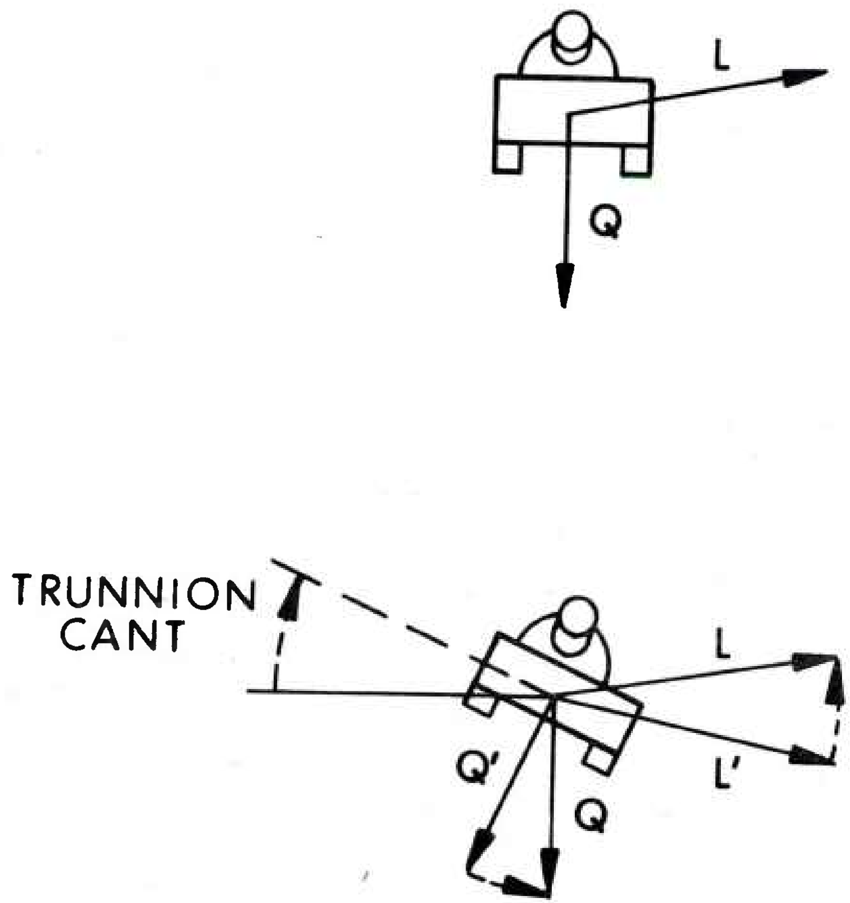


Figure 90 Stabilization of Principal F/C Corrections

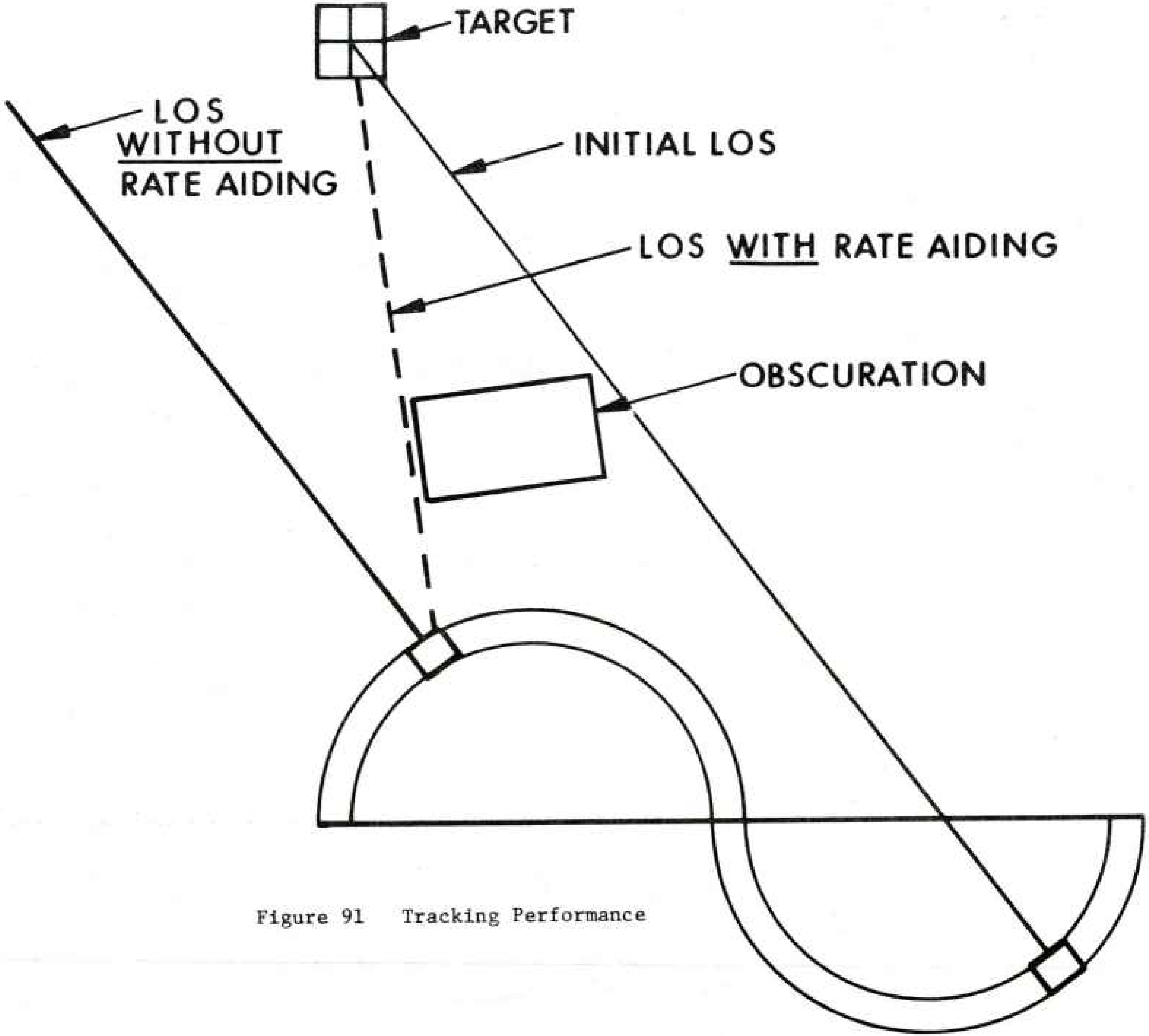


Figure 91 Tracking Performance

6.2 G.E. Investigation of Fire Control Principles

Figure 92 summarizes the undesired responses of the XM19 uncovered during the APG firing tests and the undesired responses that were anticipated before the firing tests started. As summarized:

a. Erroneous Lead on Bump Course. This effect was particularly noticeable for the stationary target case with the vehicle moving directly at the target. For such a situation, the lead angle should be zero but very frequently in the firing tests it was not zero but of sufficient value to cause large misses at the target. As will be described later, (see Figures 93 and 94) this error is caused by extreme sensitivity of the Line of Sight (LOS) rate measurement components to (1) tracking rate roughness and (2) vehicle angular motions.

b. Lead too Small, Moving Target. The lead solutions when tracking CW ranged from 80-100% of the proper value, and when tracking CCW from 70-90% of the true value. This caused the shots to consistently lag the target. This was apparently caused by insufficient sensitivity in the turret rate gyro.

c. Hysteresis in Jump and Boresight Settings. This effect was small (about .3 mil) compared to items a. and b., and was more of an annoyance than a significant error source. It is an effect that should be corrected sometime, however.

In addition, errors were anticipated on the Zig-Zag course (as shown in Figure 96). This expected error is associated with the measurement of LOS rate, with generation of lead angle, at one place on a curved path and firing at a different point. This anticipated error did not arise in the firing tests because the tests were constrained to generating lead and firing only on the straight portions of the course.

Figure 93 illustrates sensitivity to tracking rate roughness. For straight line, constant speed, target and vehicle motions, the required tracking rate is very nearly constant. However, the actual tracking rate may be quite variable due to b. jerkiness in the gunner commands to the gun servos and (2) incomplete stabilization of the gun by the gun servos when the carrying vehicle is subject to large motions.

1. ERRONEOUS LEAD ON BUMP COURSE
2. LEAD TOO SMALL, MOVING TARGET
3. HYSTERESIS IN JUMP AND BORESIGHT SETTINGS

Undesirable Responses Uncovered During Firing Tests

1. ERRONEOUS LEAD ON BUMP COURSE, SMALL SMOOTHING TIME
2. ERRONEOUS LEAD ON ZIG-ZAG COURSE, OLD RATE DATA

Anticipated Undesirable Responses

Figure 92

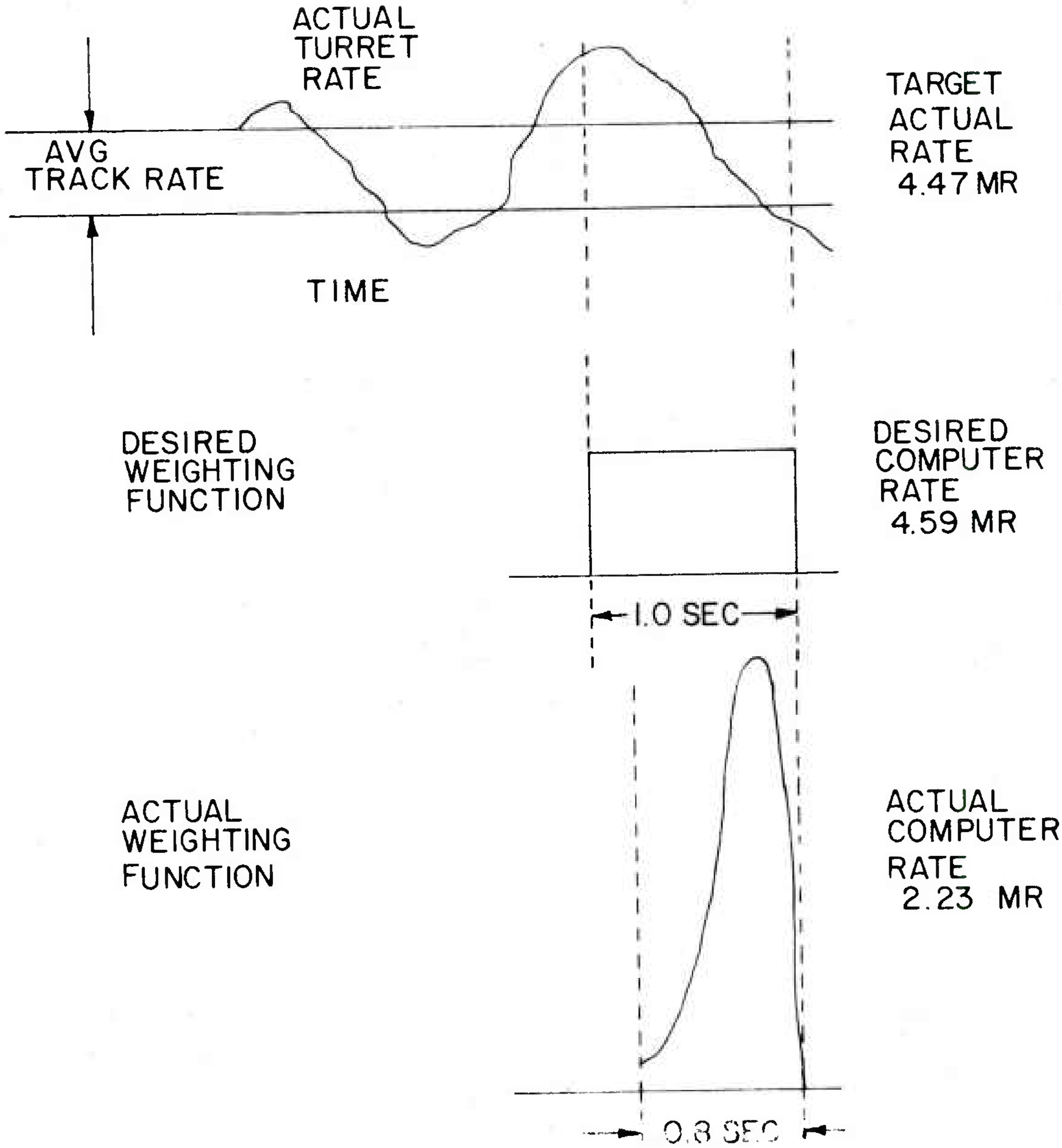


Figure 93 Tracking Rate Determination

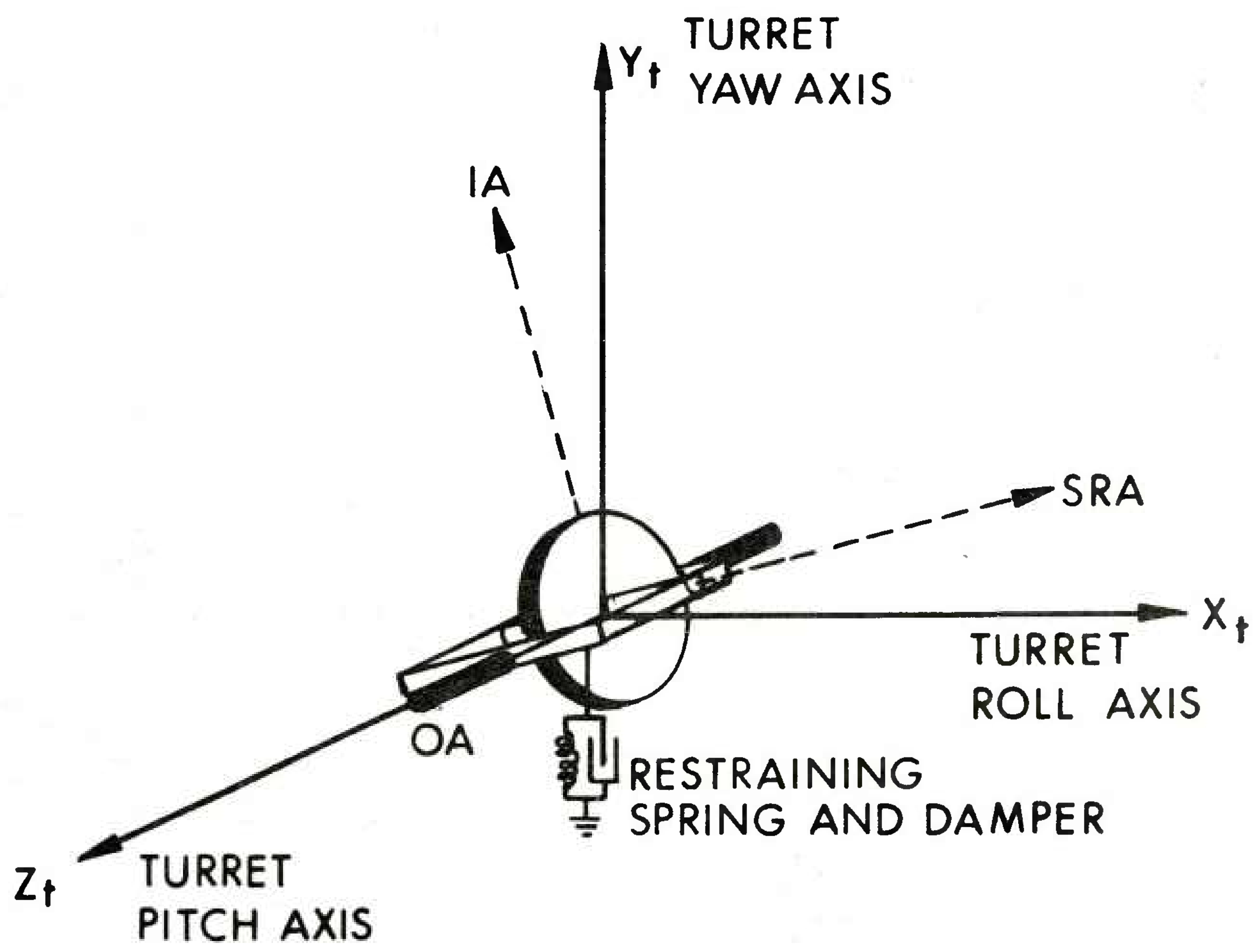


Figure 94 Schematic Diagram LOS Rate Gyro in Turret

To reduce the sensitivity to tracking rate roughness, the tracking rate should be sampled and smoothed over a long period of time. This, however, is at odds with the need to obtain a lead angle solution in a reasonable length of time. There is an inherent compromise between these conflicting requirements.

In the original exposition of the lead angle generation that appeared in FCDD-403, the weighting function of LOS rate sampling was somewhat reasonable. The sampling time of 1 second was probably too much on the low side, but was not too bad a compromise. The actual weighting function that was built into the XM19, as shown at the bottom of Figure 93 was much too peaked and short.

Figure 94 shows a schematic diagram of the rate gyro used for sensing LOS rate. (Turret yaw axis rate). This rate gyro is restrained by a relatively low gradient spring, thus allowing relatively large motions (up to 15°) about the output axis for large tracking rates (2.5 deg/sec). Under these conditions, the sensitive axis of the rate gyro is displaced from the turret yaw axis, allowing the gyro to register a portion of any turret roll motion that may exist. A more serious problem is the sensitivity to pitch motion. Since the gyro is softly sprung, the gyro does not get carried along with turret pitch motion and this relative motion on the gyro gimbal registers on the gyro pickoff as a large LOS tracking rate.

Figure 95 shows the sensitivity of the rate gyro plus filter network to pitch rate motions as a function of frequency. First of all, it is noticed that the sensitivity peaks in the 1-2 Hz region (6-12 rad/sec) which is also the frequency region of largest hull pitch motions. Secondly, a sample calculation will show the possible sensitivity to pitch rate. The peak shown in Figure 95 is approximately .05. When traveling over the bump course at 12 mph, pitch rates of .5 rad/sec are frequently encountered. The erroneous indicated tracking rate under these circumstances would be w_a = .005(.5) = .0025 rad/sec. For a shell time of flight of 2 seconds, the erroneous lead angle would be 2(.0025) = .005 rad or 5 millirad. This is, of course, a near peak situation but does show the large errors that are possible.

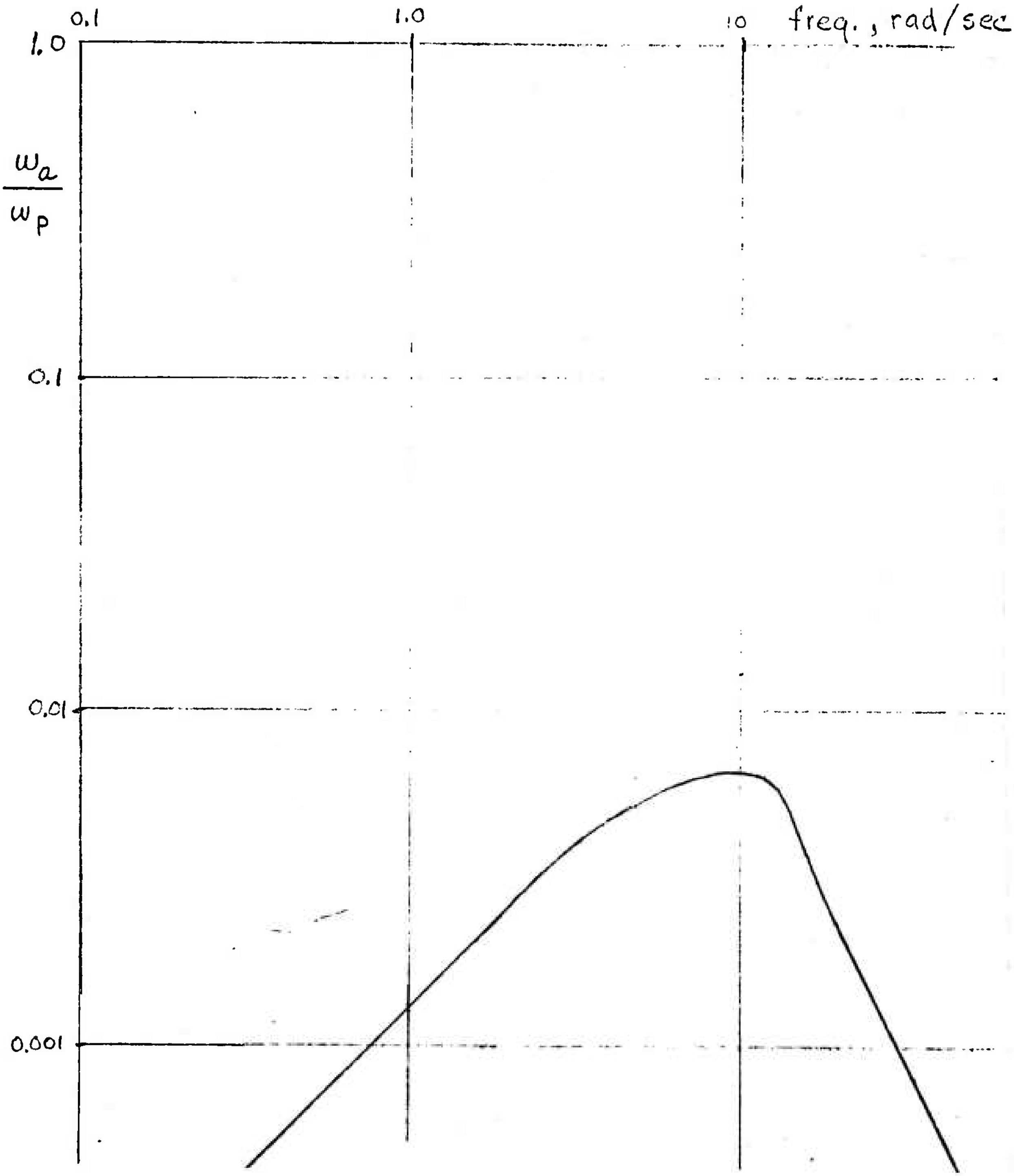
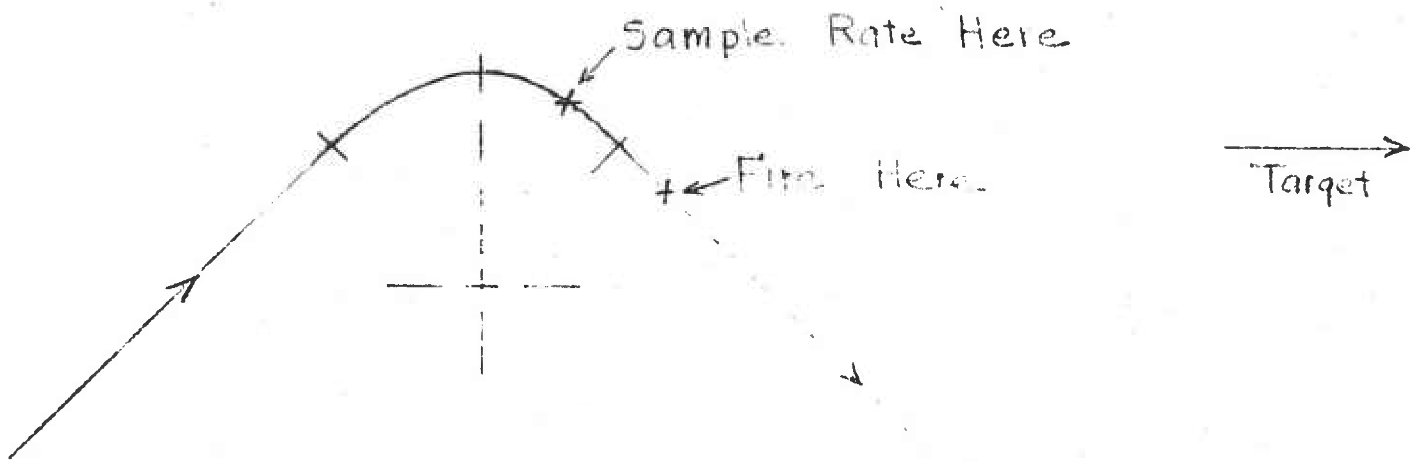


Figure 95 Sensitivity of Tracking Rate - Measurement to Pitch Rate



Target at 1500 Meters

Vehicle Speed 7 mph

Sample Rate 3/4 around turn

Error = 2.2 Meters

Figure 96 Zig-Zag Course

Figure 97 shows the positional and velocity sensitivity coefficients for the XM411 ammunition which is used in the 152mm gun on the M60A1E2, and which is one of the rounds that the XM19 ballistics computer is designed to handle. As expected, these curves show that uncertainties in position and velocity in a direction normal to the LOS are much more critical than uncertainties along the LOS. Also, the sensitivity to cross winds, while important, is much less than that due to target or own-vehicle cross velocity.

Figure 98 displays much of the same information as Figure 97, except that the information is presented in terms of angular and angular-velocity uncertainties in the LOS. It is in terms of angle and angular rates that the displacements normal to the LOS have to be measured. Of particular interest is the very large sensitivity to uncertainties in the LOS rate. It is this high sensitivity that makes the determination of lead angle so difficult. Also shown in this figure is the sensitivity to cant angle c. In this curve, only the resolution of superelevation is included. It is seen that this sensitivity is relatively low.

Figure 99 summarizes the findings.

FIGURE 97

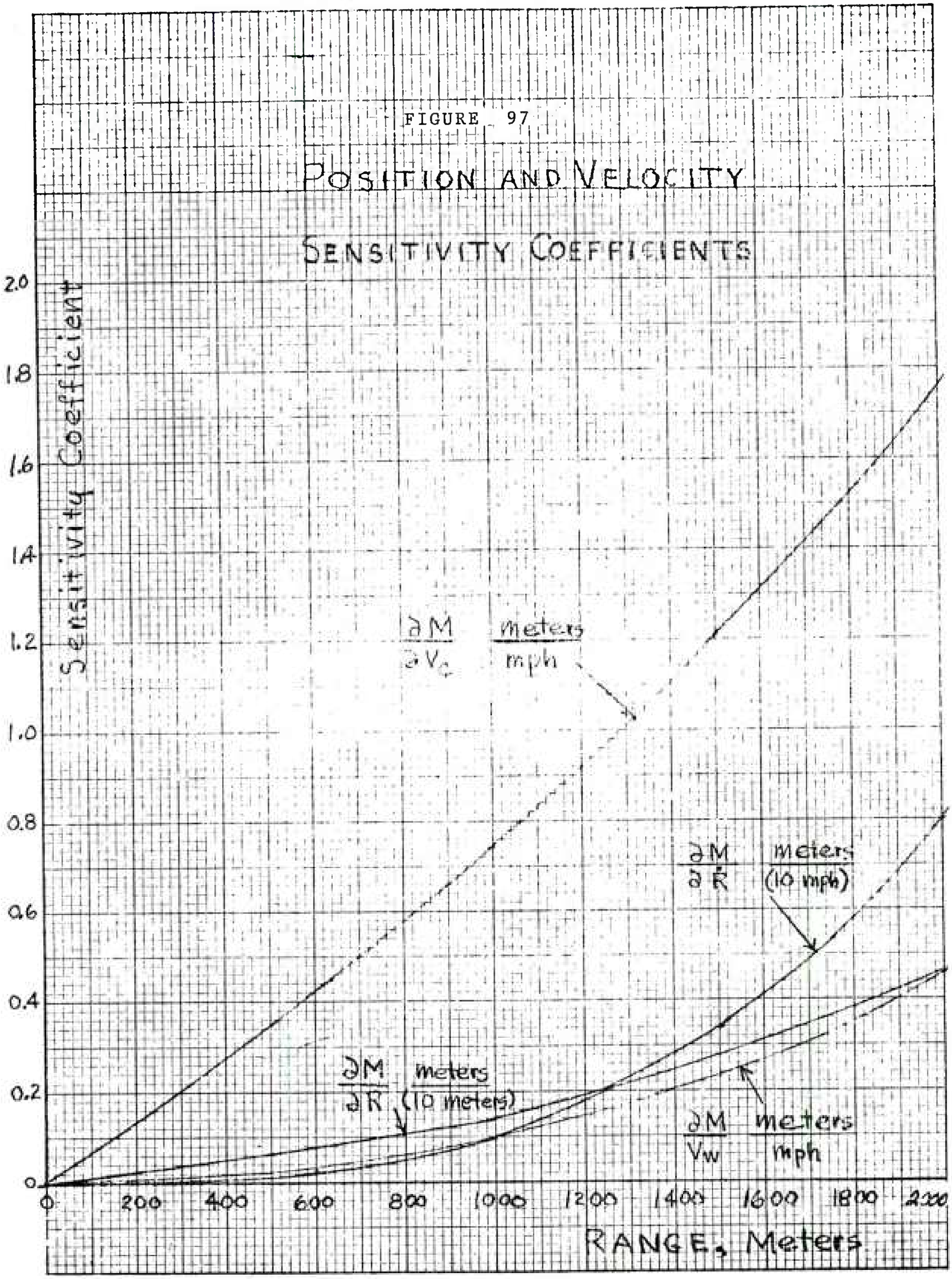
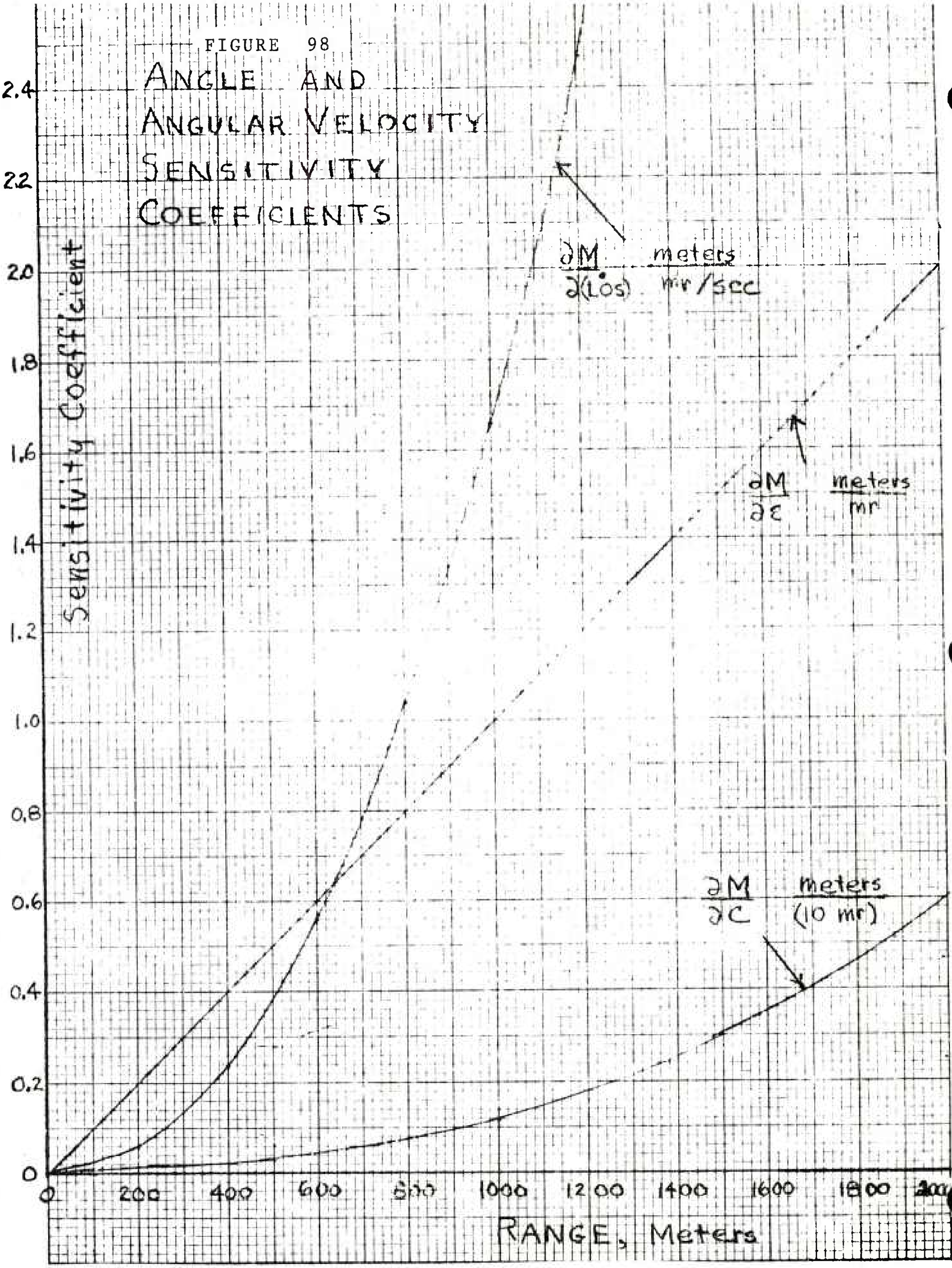

POSITION AND VELOCITY
SENSITIVITY COEFFICIENTS
Sensitivity Coefficient
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
∂M/∂Vc meters/mph
∂M/∂Ṙ meters/(10 mph)
∂M/∂R meters/(10 meters)
∂M/Vw meters/mph
0
200
400
600
800
1000
1200
1400
1600
1800
2000
RANGE, Meters

FIGURE 98


ANGLE AND
ANGULAR VELOCITY
SENSITIVITY
COEFFICIENTS
Sensitivity Coefficient
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
∂M/∂(LOS) meters/mr/sec
∂M/∂ε meters/mr
∂M/∂C meters/(10 mr)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
RANGE, Meters

1. NEED HIGH QUALITY RATE GYRO WITH HIGH NATURAL FREQUENCY

2. NEED LONGER SMOOTHING TIME - PERHAPS ADJUSTABLE WITH CONDITIONS

3. NEED FOR CONTINUOUS LEAD SOLUTION

4. ACCURATE TRACKING IMPORTANT - GUNNER NEEDS HELP

5. NEED CONTINUOUS CANT CORRECTION

6. CONCENTRATE ON INTERMEDIATE RANGES

Figure 99 Summary of Findings

6.3 HITPRO PERFORMANCE STUDIES OF FIRE CONTROL SYSTEM CONFIGURATIONS

A joint Army-GEOS investigation was conducted to investigate various tank fire control improvements. These improvements were first screened by HITPRO simulation and then the selected improvements were implemented and tested in the test bed M60A2 with the all-electric stabilization.

6.3.1 Systems Simulated

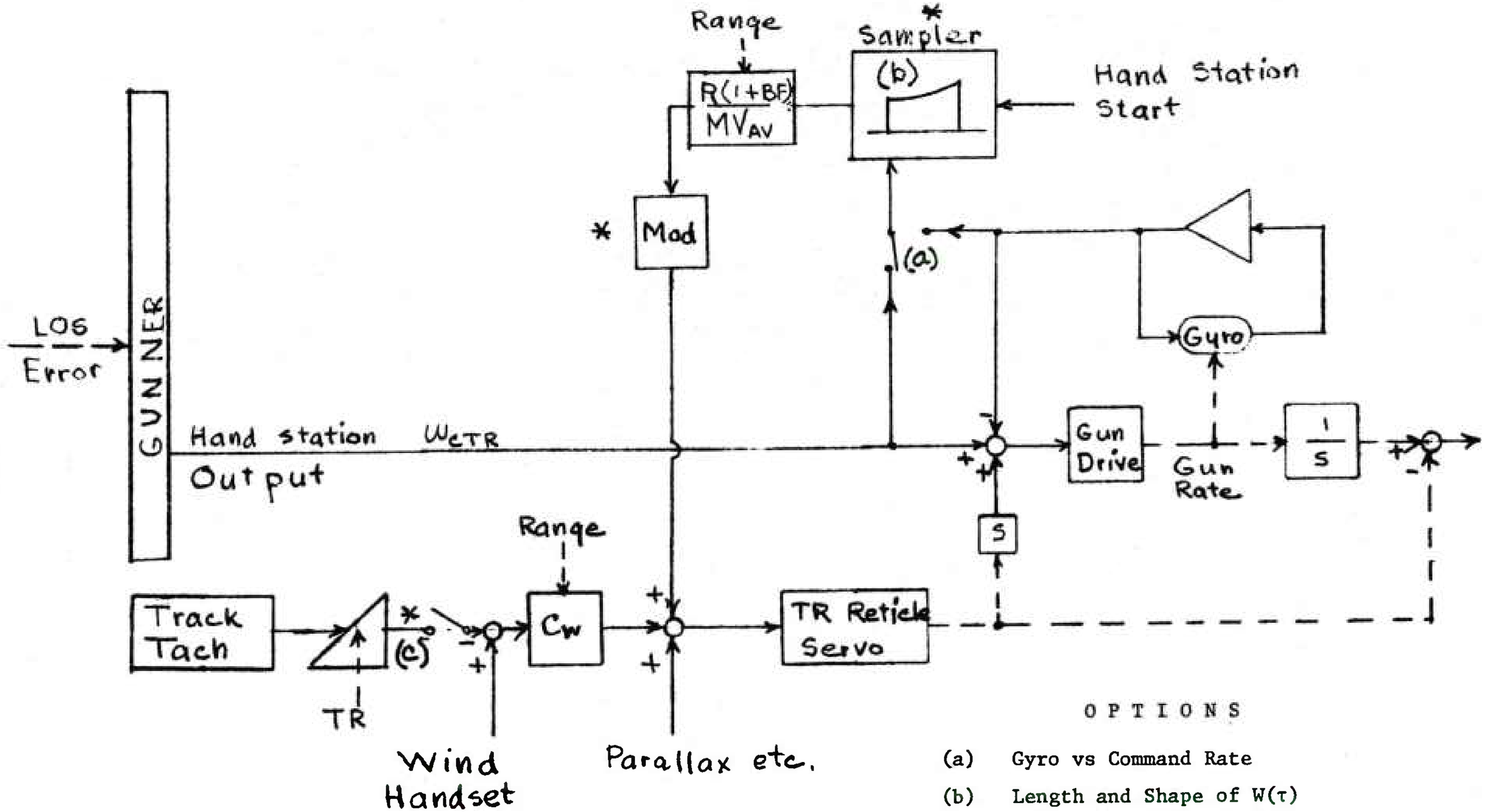
6.3.1.1 Figure 100 shows "Compulsory" System which employs a minimum modification of the present XM-19 ballistics computer.

a. Option a. gives the capability of sampling either the traverse axis gun gyro or the traverse hand station command rate signal for LOS rate for lead computation. During the 1 Apr 71 discussion, it was agreed that the option of sampling a turret rate gyro (as in the present XM-19), with differing characteristics, would also be included in the study.

b. Option b. was in regard to the length and shape of the sampling weighting function. At the 1 Apr 71 meeting, it was agreed that $W(\tau)$ would be flat topped and that the duration would be varied from .7 sec to 1.4, 2.8 and perhaps 5.6 sec.

c. Option c. was to allow correction of hand set cross-wind velocity for the effective wind due to own vehicle velocity normal to the LOS. At the 1 Apr 71 meeting, it was agreed that this correction would be in for all runs. Also, zero cross-wind would be the only hand set value.

6.3.1.2 Figure 101 shows "Compulsory" Systems Numbers 2 and 3. Both employ continuous lead angle computation. As originally presented, System 2 employed hand set of cross-wind with correction for own vehicle motion (same as for System No. 1), whereas, System 3 employed a wind sensor. At the 1 Apr 71 meeting, it was decided that the wind sensor would not be available for this contract activity and, therefore, this system would not be included in the simulation study. From this point on, the designation of Systems 2 or 3 was applied to the (a) Option of Figure 101. That is, System 2 is the continuous lead generation configuration without rate aiding to the gunner for own vehicle velocity normal to the LOS, whereas, System 3 includes rate aiding.



OPTIONS

(a) Gyro vs Command Rate

(b) Length and Shape of W(τ)

(c) Correction to Wind

Figure 100 "Compulsory" System 1

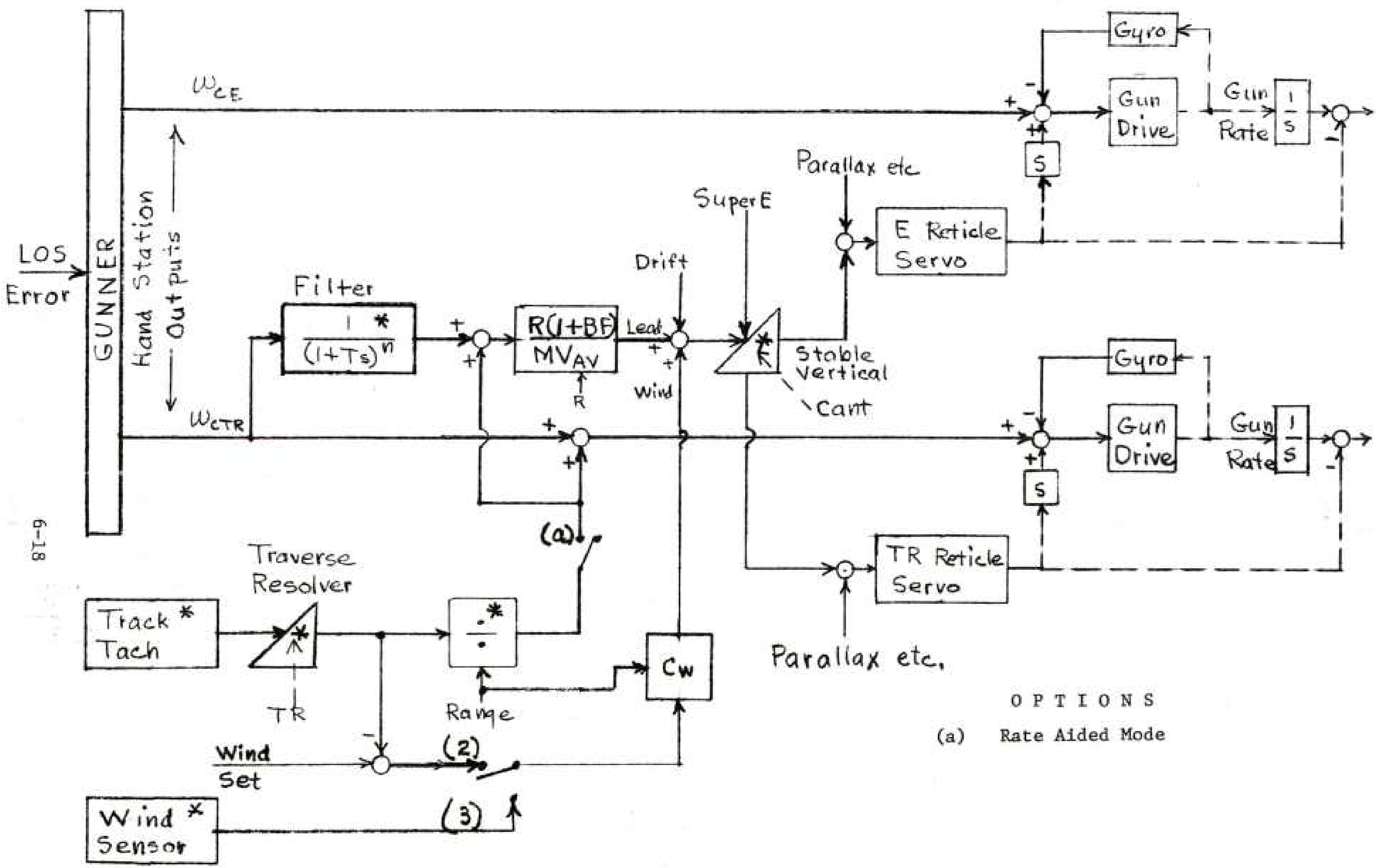


Figure 101 "Compulsory" Systems 2 & 3

6.3.2 Simulation Results

The runs were made with vehicle speed of 12 mph and target speed of zero and were all nominally 60 seconds in duration. Four different courses were used:

a. The standard APG bump course with target straight ahead.

b. The APG Zig-Zag course with target along the axis of the course. (Straight sections of the course inclined $\pm$ 45° to the course axis).

c. The APG Zig-Zag course with APG bumps superimposed.

d. The APG Zig-Zag course with "long bumps". These long bumps were trapedoidally shaped like the regular APG bumps, but higher (.8 ft. = almost 10 inches) with a longer slope (5 ft.) and a very long top (290 ft.). These bumps were alternated for the left and right tracks to induce appreciable cant motions (7° or so).

Most of the runs were made with two modes in the nominal firing sequences:

a. 4-second delay at start; 1.5-second delay after range reset; 1.5-second delay after lead sample; 0.2-second delay after shot burst.

b. 5-second delay at start; 2-second delay after range reset; 2-second delay after lead sample; 0-delay after shot burst.

These modes were intended to give a greater sampling of possible conditions existing during a run. However, this is the nominal or minimum spacing of events. The firing sequence is further delayed if, for any reason, the gun does not appear to the gunner to be pointed correctly. In some instances, the pointing error response dominated the sequencing of firing events, tending to synchronize the firing sequence with course disturbances rather than the time sequence.

Figures 102 through 110 show the results of System No. 1 performance on the bump course. During these runs, the lead angle solution should be zero. Vehicle motions induce errors principally through three channels:

a. Sensitivity of the turret gyro to pitch motions.

b. Sensitivity of the turret gyro to roll motions.

c. Incomplete stabilization of the gun in the traverse channel.

Figure 102 shows the lead solution (error) obtained at various points during the 60-second runs when the turret gyro was sampled for 0.7 second. The errors are generally far too large, but are particularly large in the

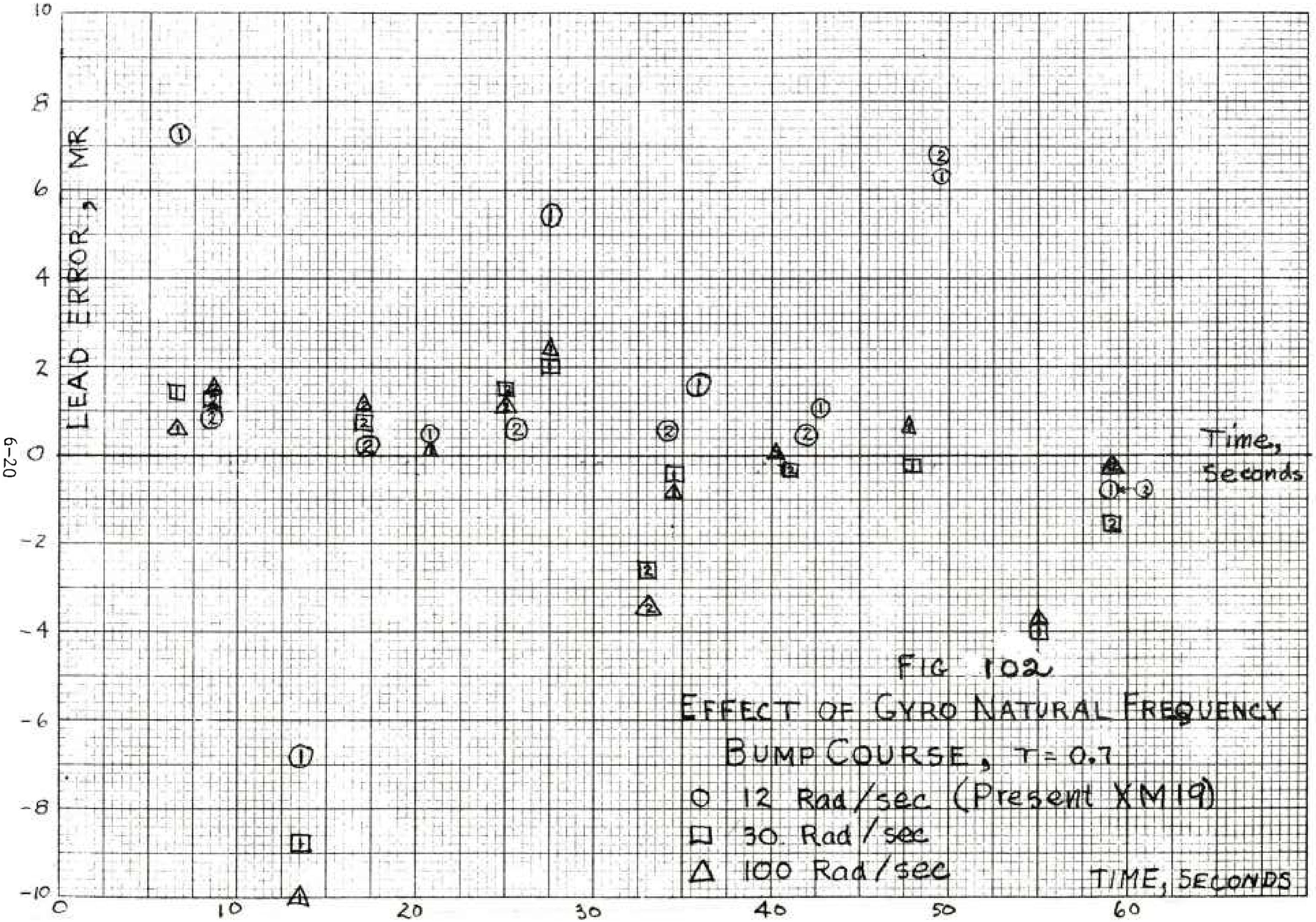


FIG 102
EFFECT OF GYRO NATURAL FREQUENCY
BUMP COURSE, $\tau = 0.7$

0-15 second and 49-54 second time periods as these are particularly rough portions of the bump course, causing frequent impacting of the suspension stops. There is no clear change in error with turret gyro natural frequency. This is borne out in Figure 103 in which the result of Figure 102 are plotted as the average hit probability of all the shots of the run versus gyro natural frequency. The two curves of Figure 103 are for Mode 1 and Mode 2 runs. A slight improvement with increased gyro natural frequency is indicated. Gyro natural frequency should improve only Item b. above (Sensitivity of the turret gyro to roll motions). Thus, apparently in these runs, this is not the important source of error.

Figure 104 shows the effect of increasing the sample time to 1.4 and 2.8 seconds. Generally, the performance is improved by increasing the time from 0.7 to 1.4 seconds. The further increase to 2.8 seconds does not appear as beneficial.

Figure 105 shows the response of the system when the traverse gun gyro (LOS gyro) is sampled rather than the turret rate gyro. Since the gun is largely stabilized, this gyro should not be sensitive to pitch and roll motions. It is seen that this response does not contain the very large errors that occur in Figure 104 in the very rough portions of the bump course, but that in the more common parts of the course, the errors are not particularly improved. The conclusion of all this is that there is no great difference in sampling either the turret or the gun gyro for lead determination, and that the largest source of error is the incomplete stabilization of the gun. An interesting corollary is that a gun stabilization system which is satisfactory for pointing of the gun may not be adequate for sampling pointing rate for lead angle determination, unless more sophisticated filtering is employed.

The "more sophisticated filtering" methods tried in the system studies were really different sampling procedures. Figure 106 shows the results of Conroy Sampling. In this sampling, the start of the LOS rate period is determined as before, namely when, after the proper delay time, the gun pointing error is within a particular tolerance (0.2 mr for these runs). However, the sampling period does not end at a fixed time only but after a minimum time and when the pointing error is again (or still) within tolerance.

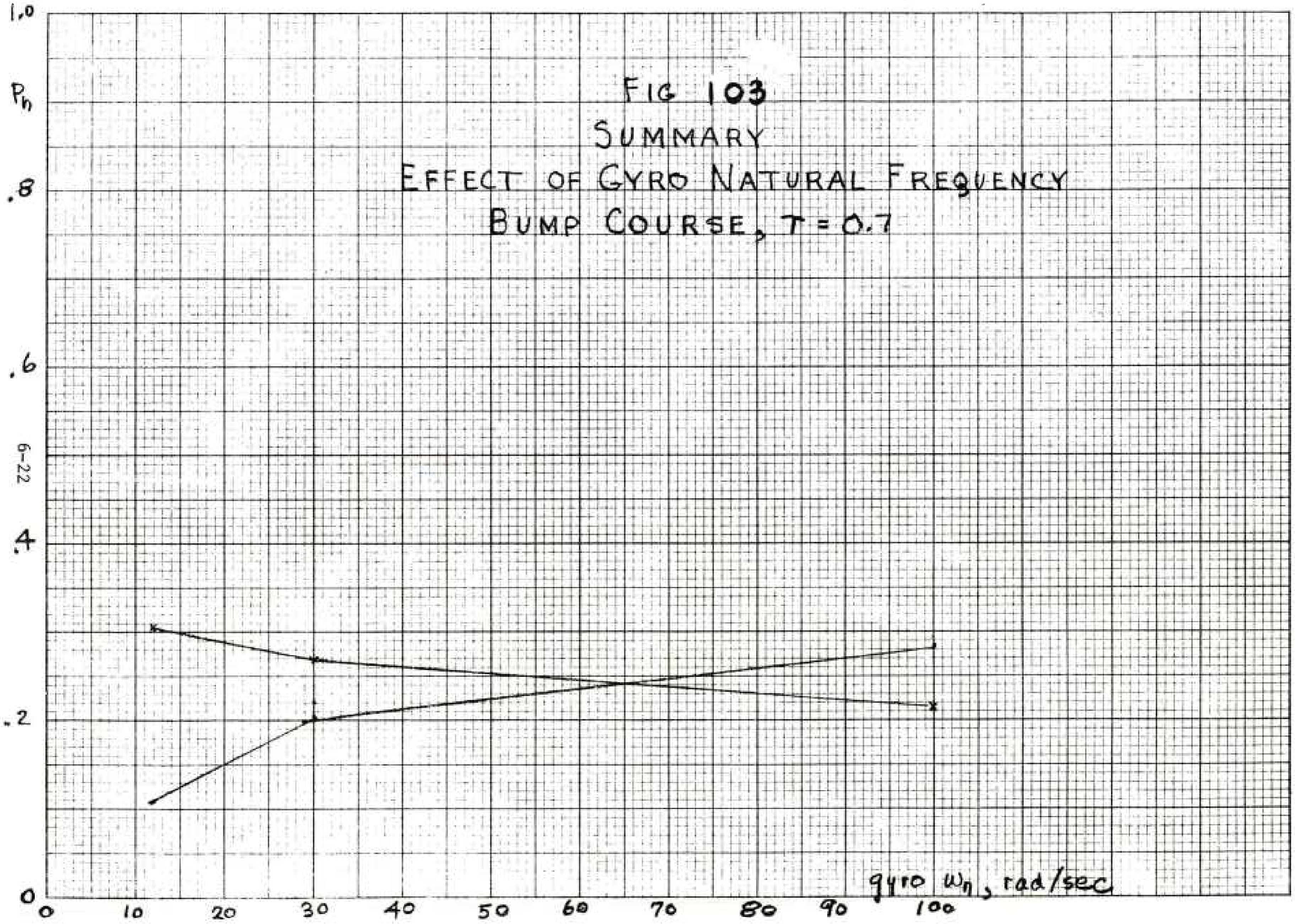


FIG 103
SUMMARY
EFFECT OF GYRO NATURAL FREQUENCY
BUMP COURSE, $T = 0.7$

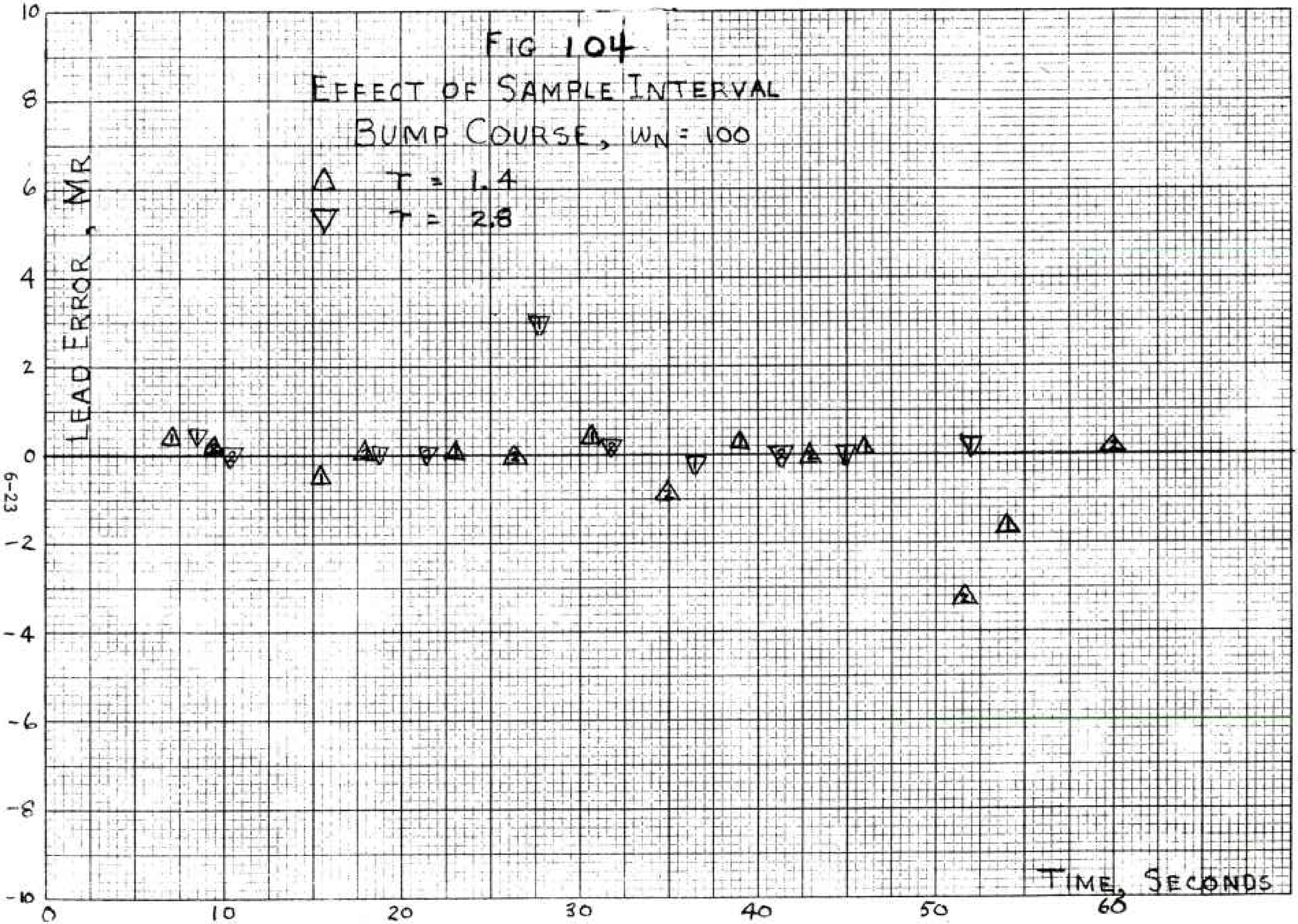


FIG 104
EFFECT OF SAMPLE INTERVAL
BUMP COURSE, ω_N = 100
△ T = 1.4
▽ T = 2.8
LEAD ERROR, MR
TIME, SECONDS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60

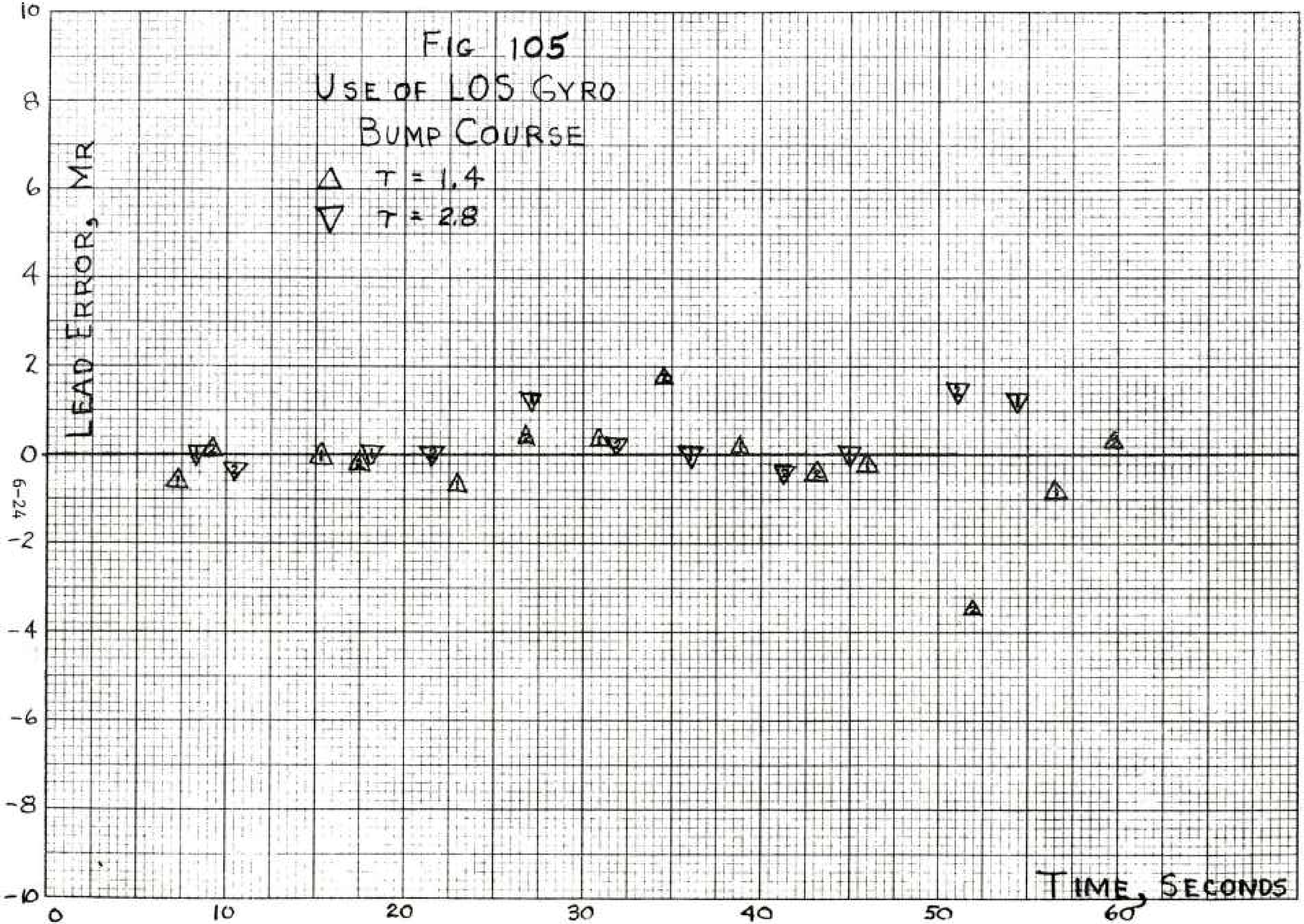


FIG 105
USE OF LOS GYRO
BUMP COURSE
T = 1.4
T = 2.8
LEAD ERROR, MR
TIME, SECONDS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60

6-24

The ballistics computer is then required to adjust the lead solution for the actual sample interval. This procedure is intended to insure that the average LOS rate during the sample is correct (except for a small aiming tolerance). The results shown in Figure 106 showed some unexpectedly large lead solution errors. The large error occurring at 51.5 seconds was analyzed in detail to determine its cause. Figure 107 shows the visual error (actual geometric pointing error) during this sample along with the threshold that the gunner employs in starting and stopping the sample. The cause of the lead error is that the gunner has a delay (0.1 seconds in these runs) in seeing and responding to the visual error. Thus, when his response is going through the threshold, the actual pointing error is quite large. Two things were tried to improve the overall response:

a. An attempt was made to insure sampling over integral cycles of the error curve by setting the minimum sample time just short of a multiple of the natural period of the error curve. That is, 1 second, 2 seconds, etc., instead of 1.4 to 2.8 seconds.

b. The gunner's time delay was reduced from 0.1 second to 1/30 second.

The results of these two modifications are shown in Figure 108. The first makes little difference, apparently because the period of the error response is not constant but dependent on the disturbing occurrences.

The improved gunner does do a much better job. The question, of course, is whether a gunner can be trained to anticipate and compensate for his own inherent delays to the extent required. The bulk of existing data on human response indicates that he could not since the HITPRO gunner constants are based on the best generally-attainable performance in similar tracking functions.

The second sampling improvement tried was that of hand station command rate sampling. In this case, the improved filtering results from the gunner ignoring the cyclical visual errors which he "knows" to be caused by vehicle angular motions. Results of this are shown in Figure 109, and are very good. Tests on the bump course at APG confirm that the gunner will not respond to transient pointing errors, thus, the results of Figure 109 are confirmed. (The gunner's ability to filter vehicle noise in other situations such as moving target or Zig-Zag course is not as well confired, but there is

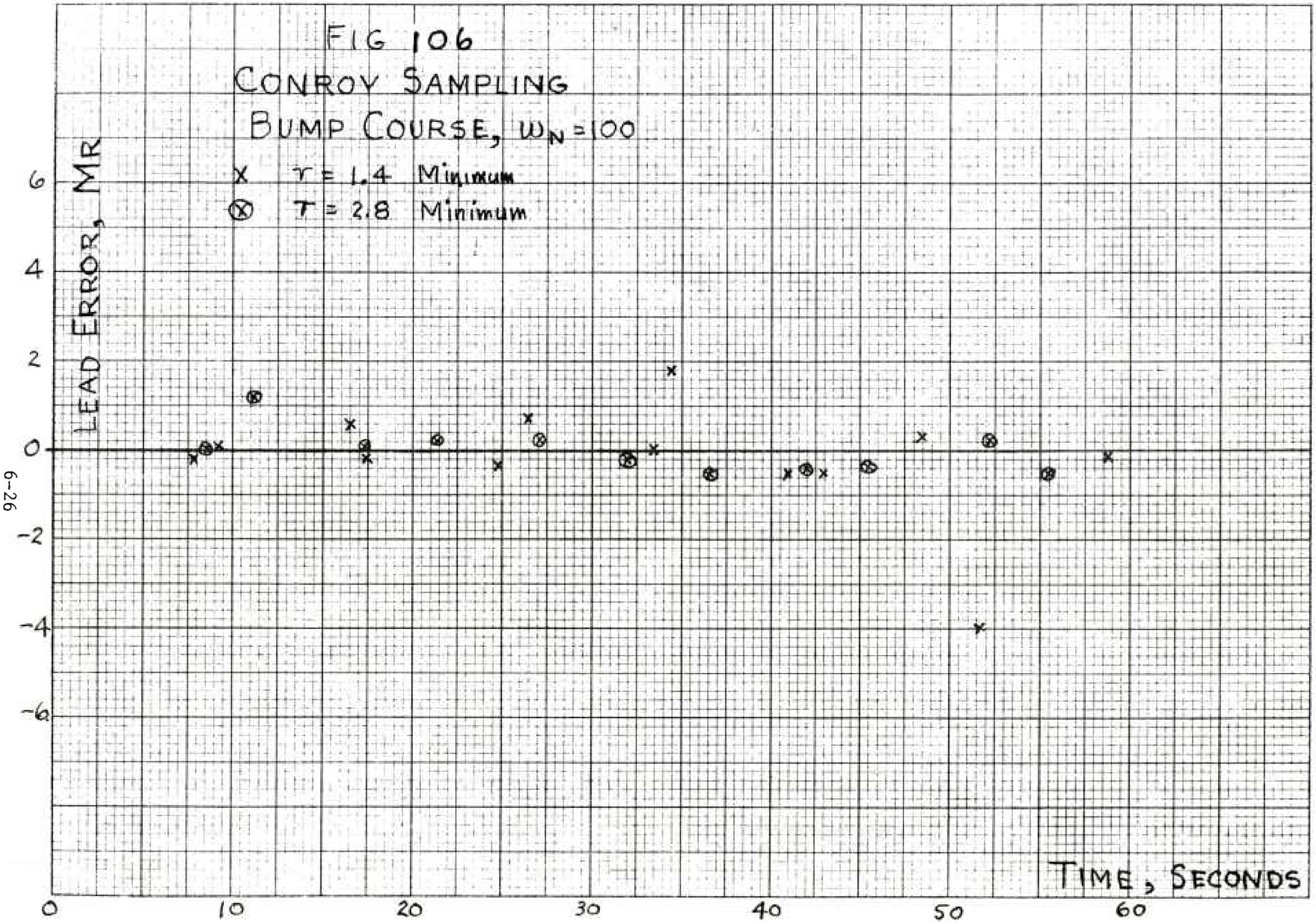


FIG 106
CONROY SAMPLING
BUMP COURSE, $\omega_N = 100$
X τ = 1.4 Minimum
⊗ τ = 2.8 Minimum
LEAD ERROR, MR
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
TIME, SECONDS

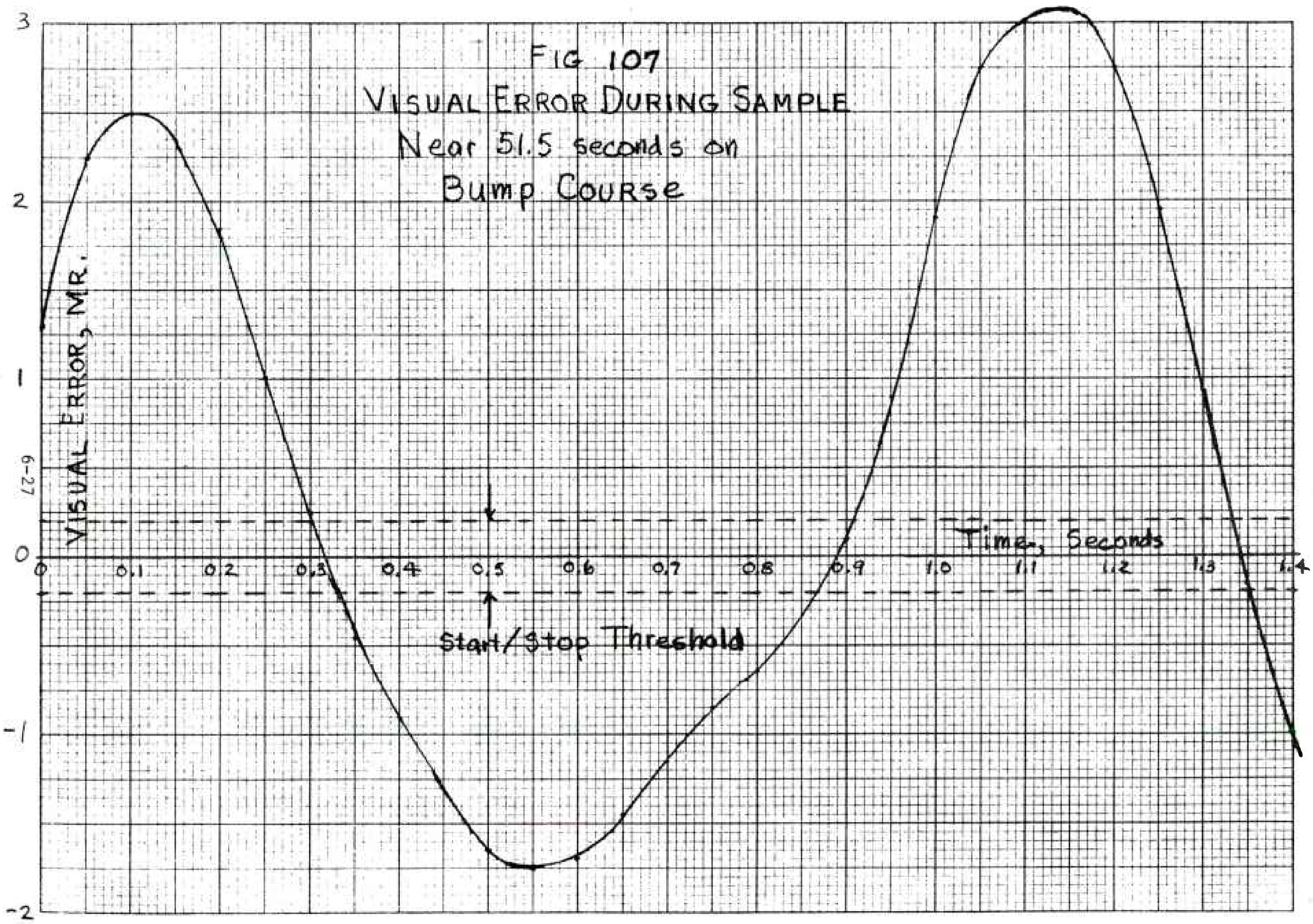
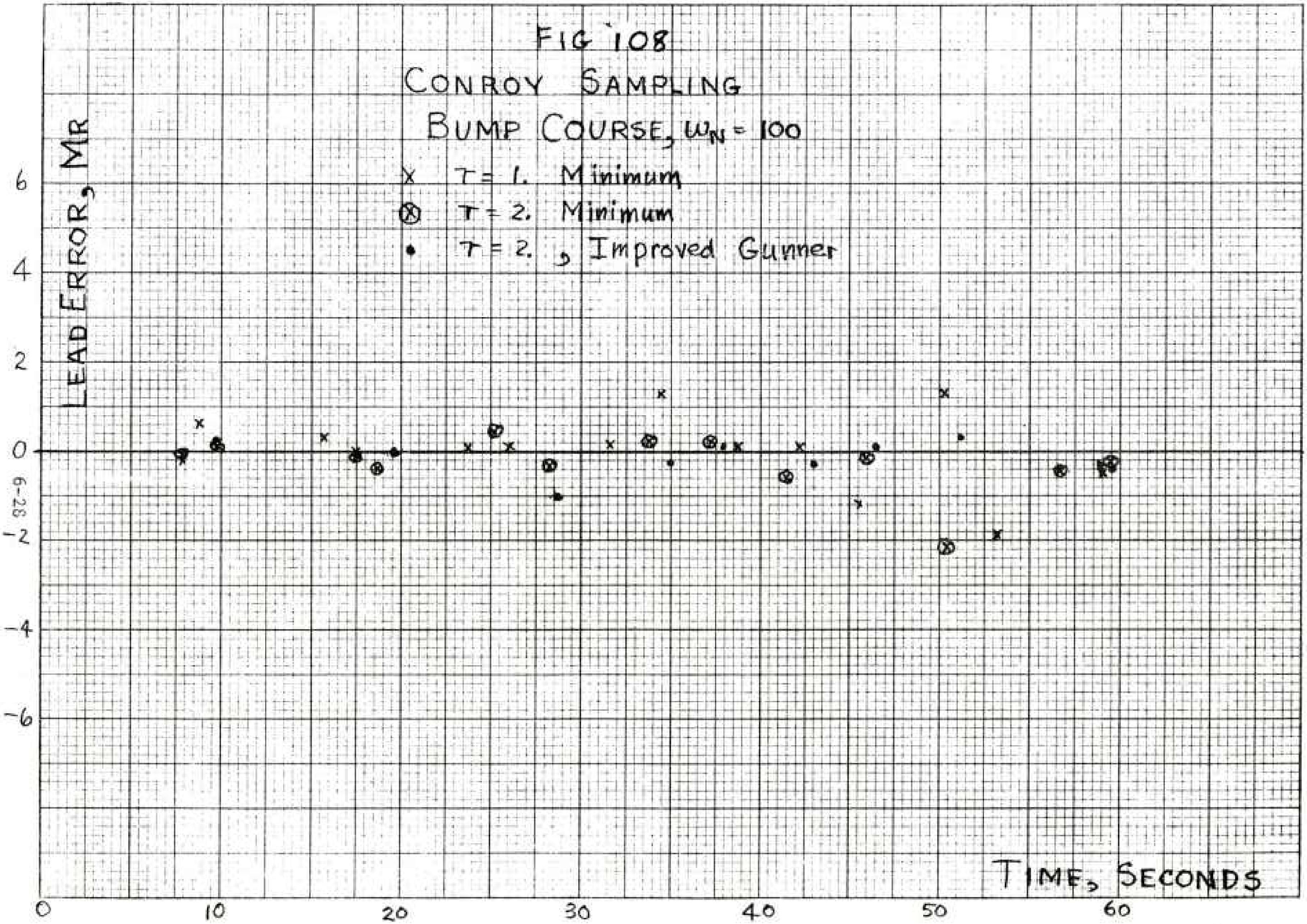


FIG 107
VISUAL ERROR DURING SAMPLE
Near 51.5 seconds on
Bump Course
VISUAL ERROR, MR.
Time, Seconds
Start/Stop Threshold
3
2
1
0
-1
-2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

FIG 108

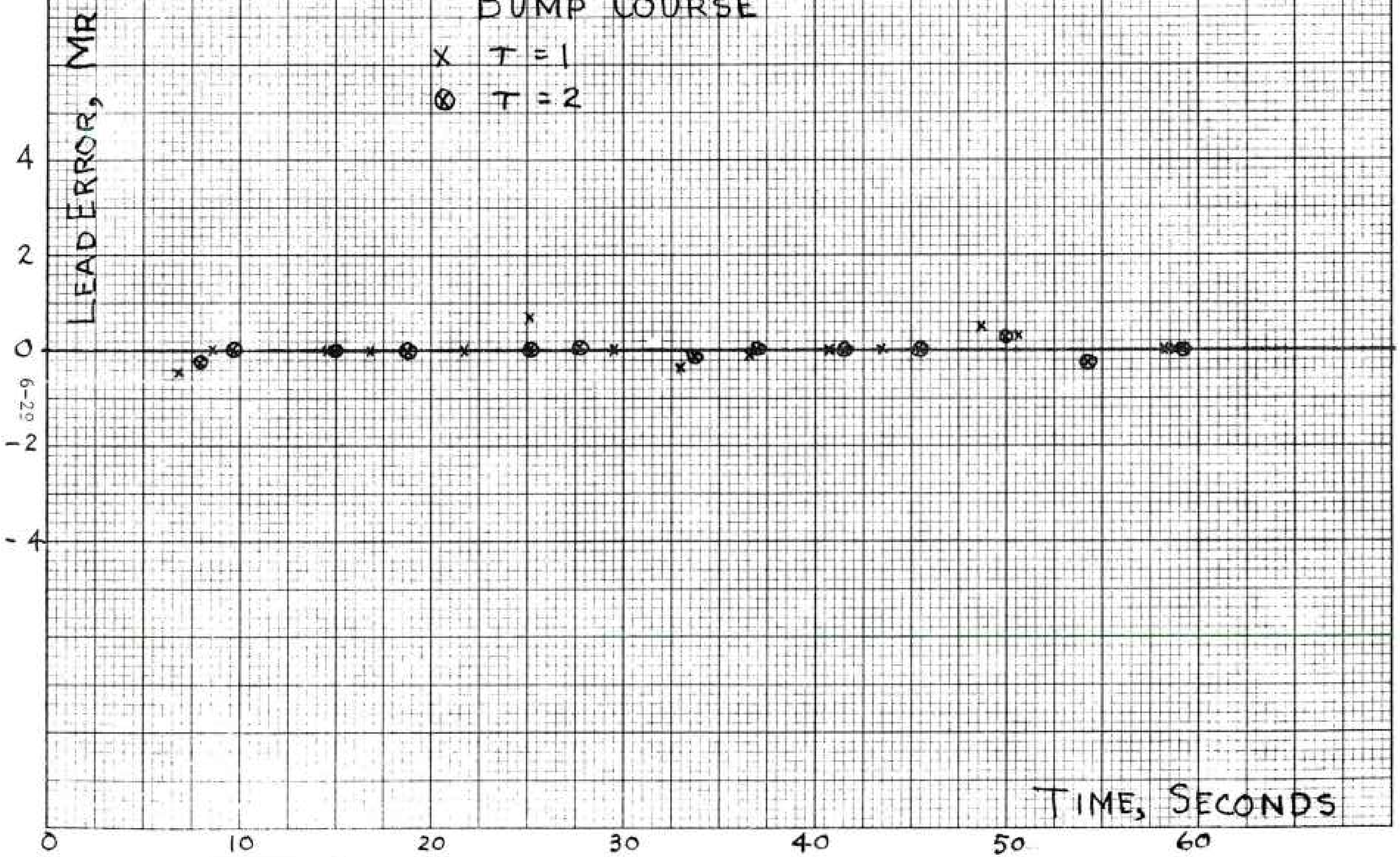


CONROY SAMPLING
BUMP COURSE, $\omega_N = 100$
× $\tau = 1.$ Minimum
⊗ $\tau = 2.$ Minimum
• $\tau = 2.$, Improved Gunner
LEAD ERROR, MR
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
TIME, SECONDS
6-28

Fig 109

Hand Station Sample

Bump Course



considerable evidence to indicate that he filters quite well in these situations, also. Of course, in tracking situations he adds his own "noise" to the response).

Figure 110 is a summary of results for the bump course. Average hit probability for the run versus sampling time is plotted. Generally, a slight improvement with increased sampling time is noted. Obviously, the more important improvement is in the method of sampling.

At this point in the study, the System 1 modification which performed best on the bump course, namely the hand station sample, was tried on the Zig-Zag course. These results are shown in Figures 111 and 112, which are plots of horizontal miss versus time. Each shot in a burst is shown as a dot, with the mean of the burst shown as a cross within a circle. The heavy bars on the zero miss line denote the periods of time that the vehicle is making a turn between straight sections of the Zig-Zag course. Figure 111 shows that the Hand Station Sample System does very well on the straight aways, but does very poorly on turns. This is because the LOS rate and lead angle determined during the sample are not proper when the burst is fired two or more seconds later. Figure 112 shows the improvement that can be made by reducing the minimum delay between lead reset and firing to 0.5 seconds. It is believed that this may be better performance than a real gunner can achieve. However, the errors are still quite large and the next part of the effort was to study the performance of continuous lead angle systems on the Zig-Zag course. (See Figures 113-117).

Whenever a continuous lead angle generation is tied into a tracking system, there is always the possibility that this addition will change the "feel" of the tracking system to the gunner, thus adversely affecting his performance. Figure 113 shows the pertinent functional relationships. The top diagram shows the present arrangement in which the lead, generated from a sampled LOS rate, is entered into the system as a step function. The change in vehicle position is fed simultaneously into gun drive and into changing the apparent LOS. As is well known from the APG tests, there is a transient jiggling of the target apparent to the gunner when lead is inserted but the transient has died out before the gunner can

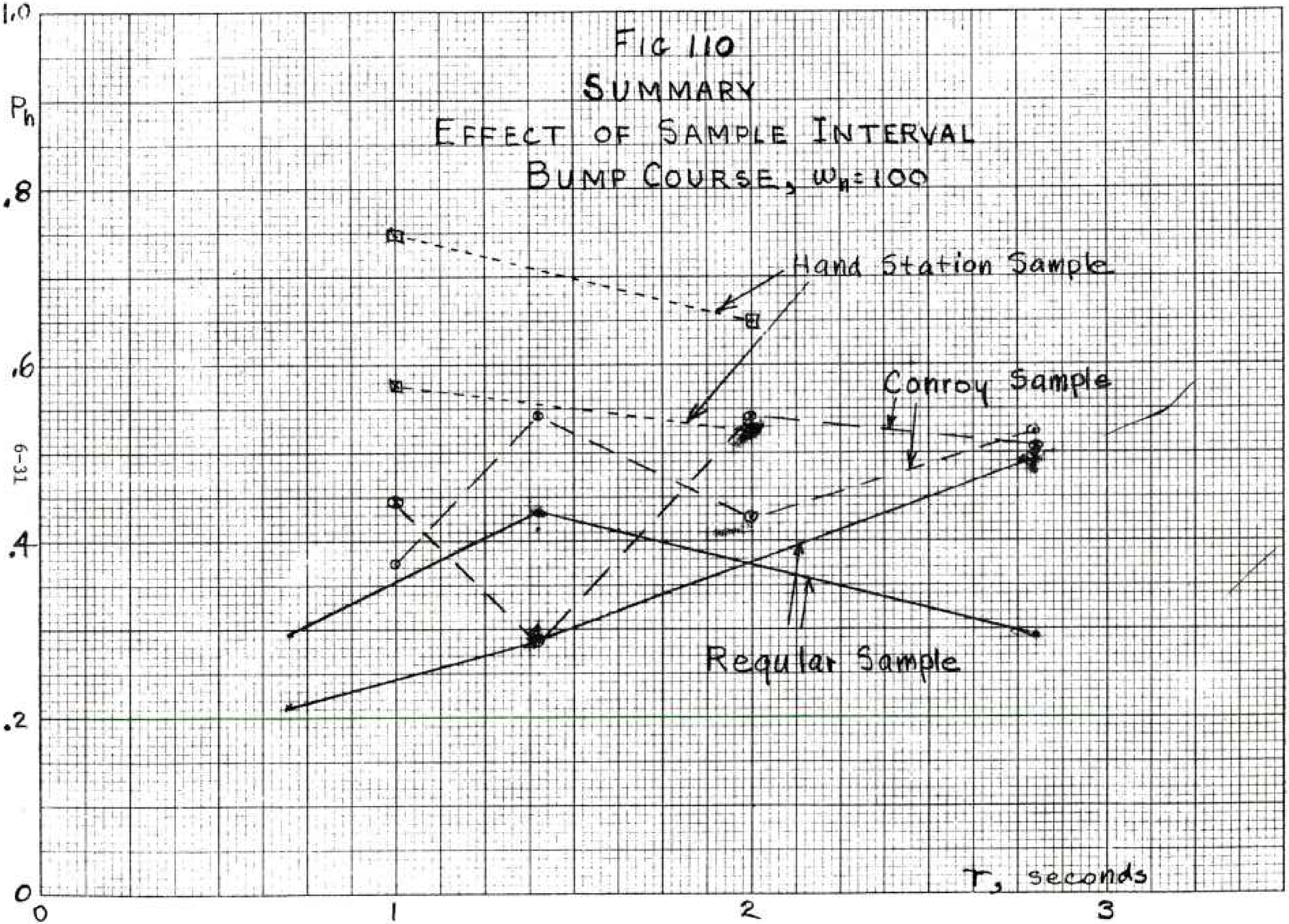


FIG 110
SUMMARY
EFFECT OF SAMPLE INTERVAL
BUMP COURSE, $\omega_n = 100$
Hand Station Sample
Conroy Sample
Regular Sample
P_h
1.0
.8
.6
.4
.2
0
1
2
3
T, seconds

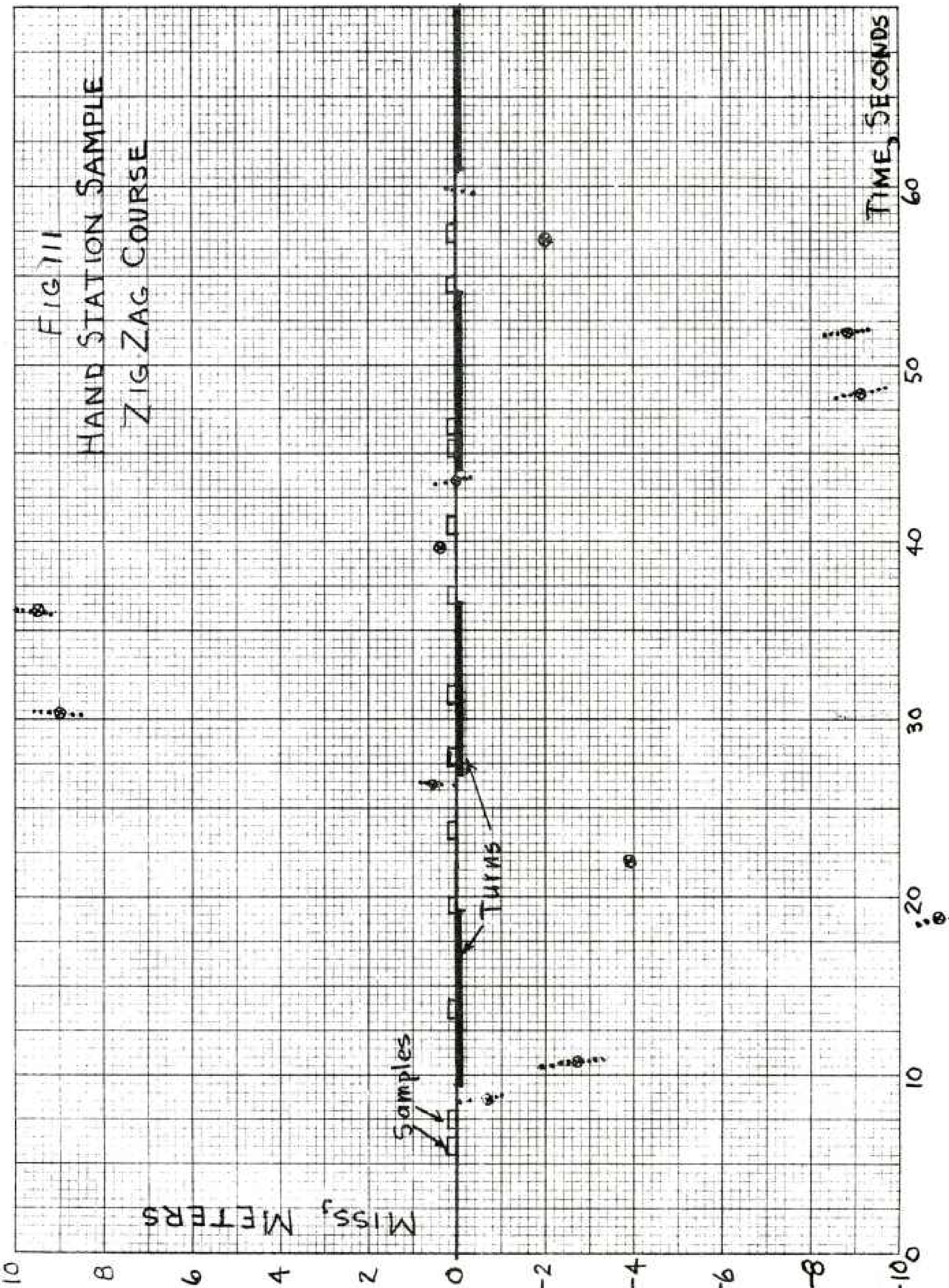


FIG III
HAND STATION SAMPLE
ZIG ZAG COURSE
MISS, METERS
TIME, SECONDS
Samples
Turns
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60

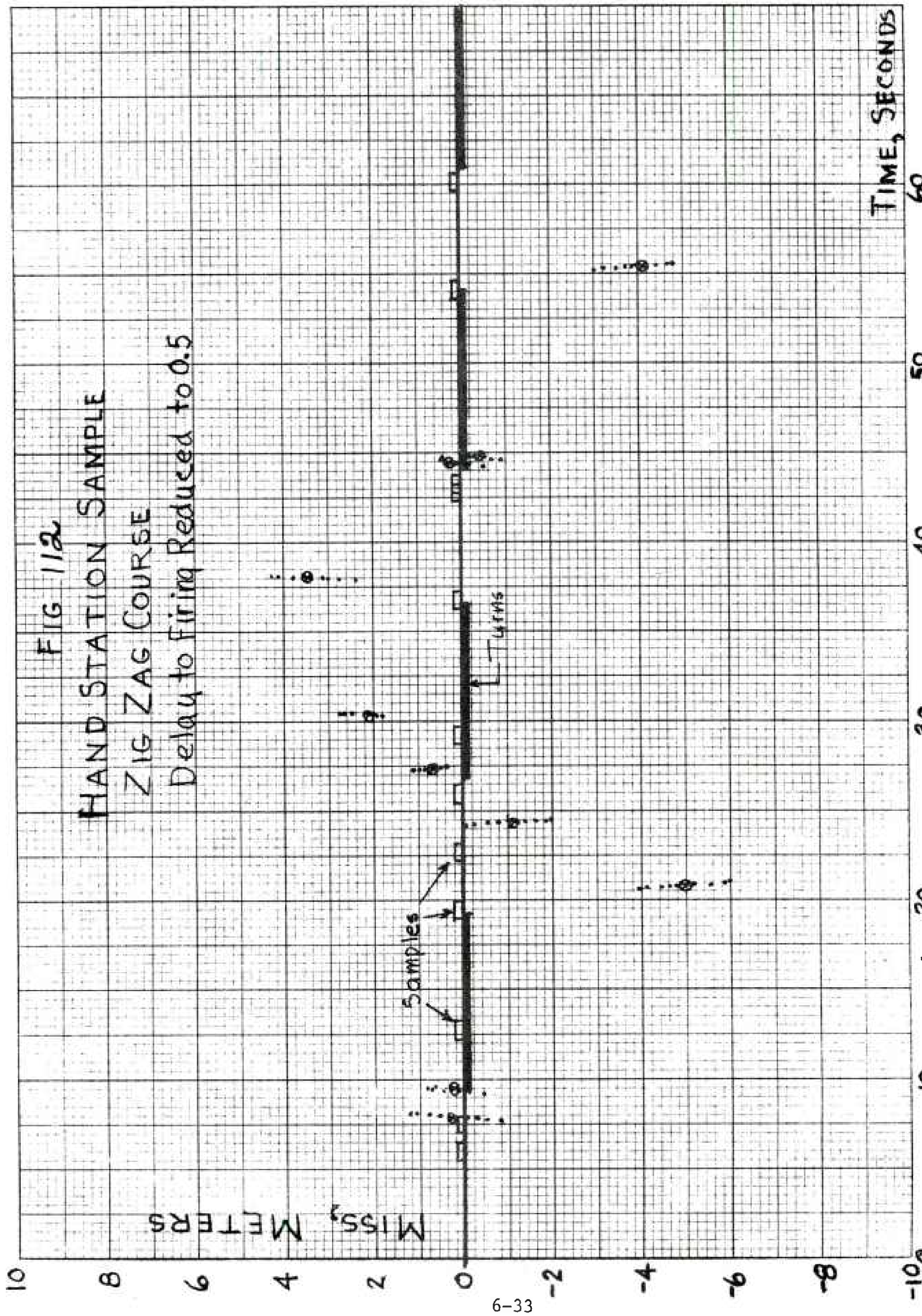
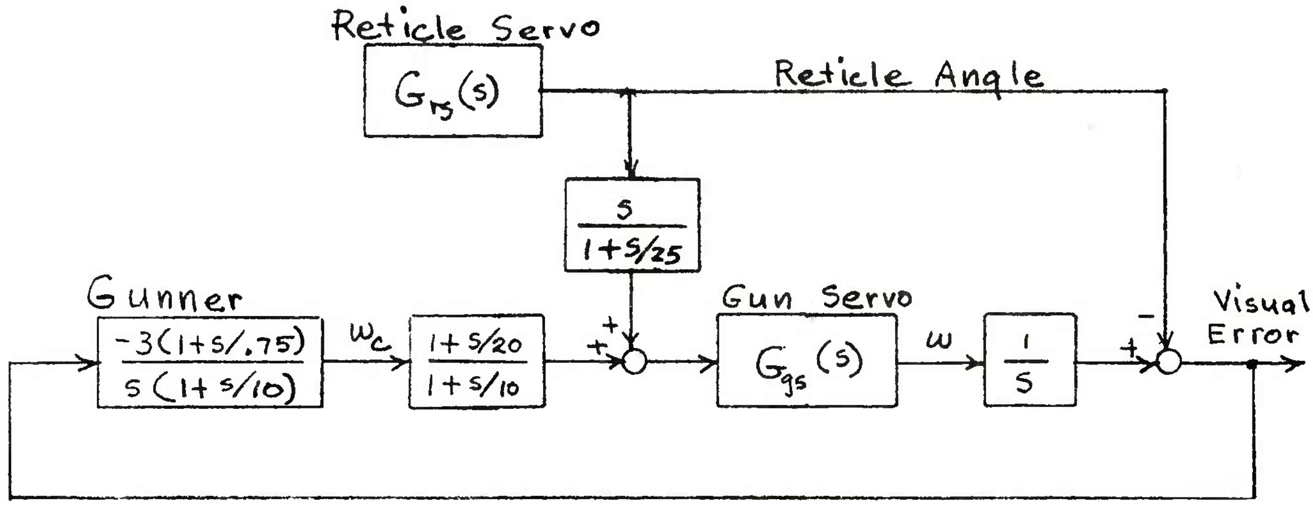
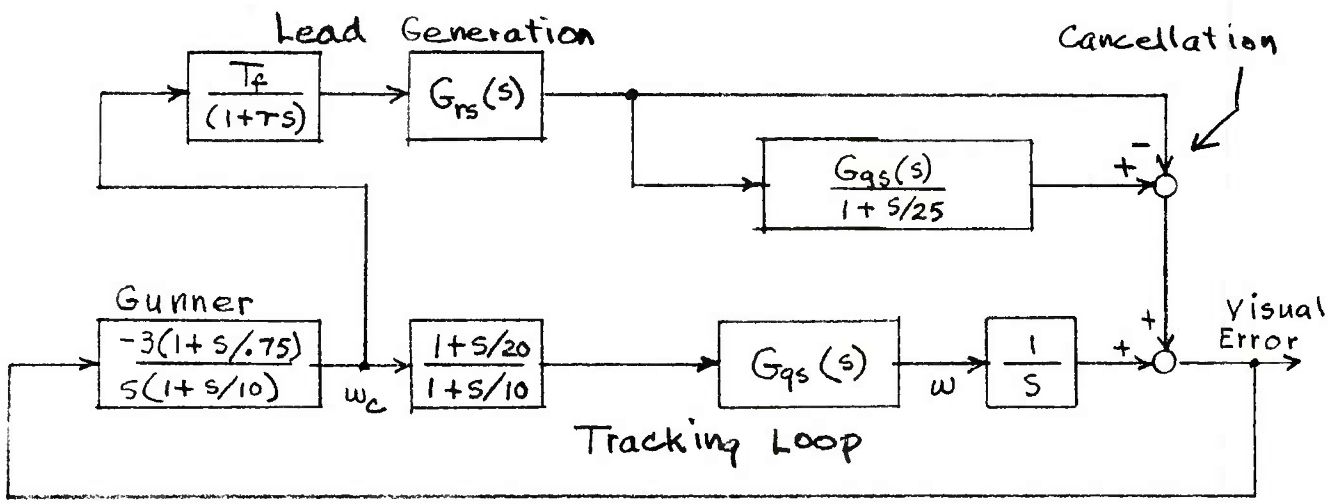


FIG 112
HAND STATION SAMPLE
ZIG ZAG COURSE
Delay to Firing Reduced to 0.5
Samples
Turns
MISS, METERS
TIME, SECONDS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60



SYSTEM WITH XM19



SYSTEM WITH CONTINUOUS LEAD

FIG 113

DYNAMICS OF CONTINUOUS LEAD

respond to it. The bottom diagram of Figure 113 represents a linear transformation of the top diagram plus the addition of continuous sampling from the hand station signal. In this diagram, it is seen that the tracking loop involving the gunner is unchanged at the frequencies to which the gunner is responsive if there is proper cancellation out to high frequencies in the parallel lead generation branch. In the actual simulation runs, it was found that there was less cancellation than anticipated due to high friction in the traverse drive, and this could cause tracking instability unless there was considerable filtering in the lead generation branch. In the real life situation, it is believed that the gunner will adaptively change his characteristics to compensate for some change in system response. However, in the simulation study, it was felt that it was necessary to maintain the same, highly-responsive, gunner-transfer function that had been used in previous parts of the study. Thus, the hand station signal was filtered with a quadratic network of the form.

$$e_o/e_i = \frac{1}{1 + \frac{2\zeta s}{\omega_f} + \frac{s^2}{\omega_f^2}}$$

instead of the simple $1/(1 + \tau s)$ form shown in Figure 113.

The individual shot impacts for continuous lead System No. 2 are shown in Figure 114. This is for the case of $\omega_f = 1.5$ damping factor, $\zeta = 1$. It is seen that the misses are relatively large following a change in tracking requirements, such as the start of a turn or the start of a straightaway. The errors tend to decrease as a particular turning rate is maintained.

Figure 115 is a similar set of results for System No. 3. The improvement in performance due to rate aiding through measurement of own vehicle velocity normal to the LOS is readily apparent.

Figure 116 is a summary of a number of different systems on the Zig-Zag course and is presented as average hit probability during the run versus sample time, or for the continuous systems, the inverse frequency. Several general conclusions are reached from Figure 116.

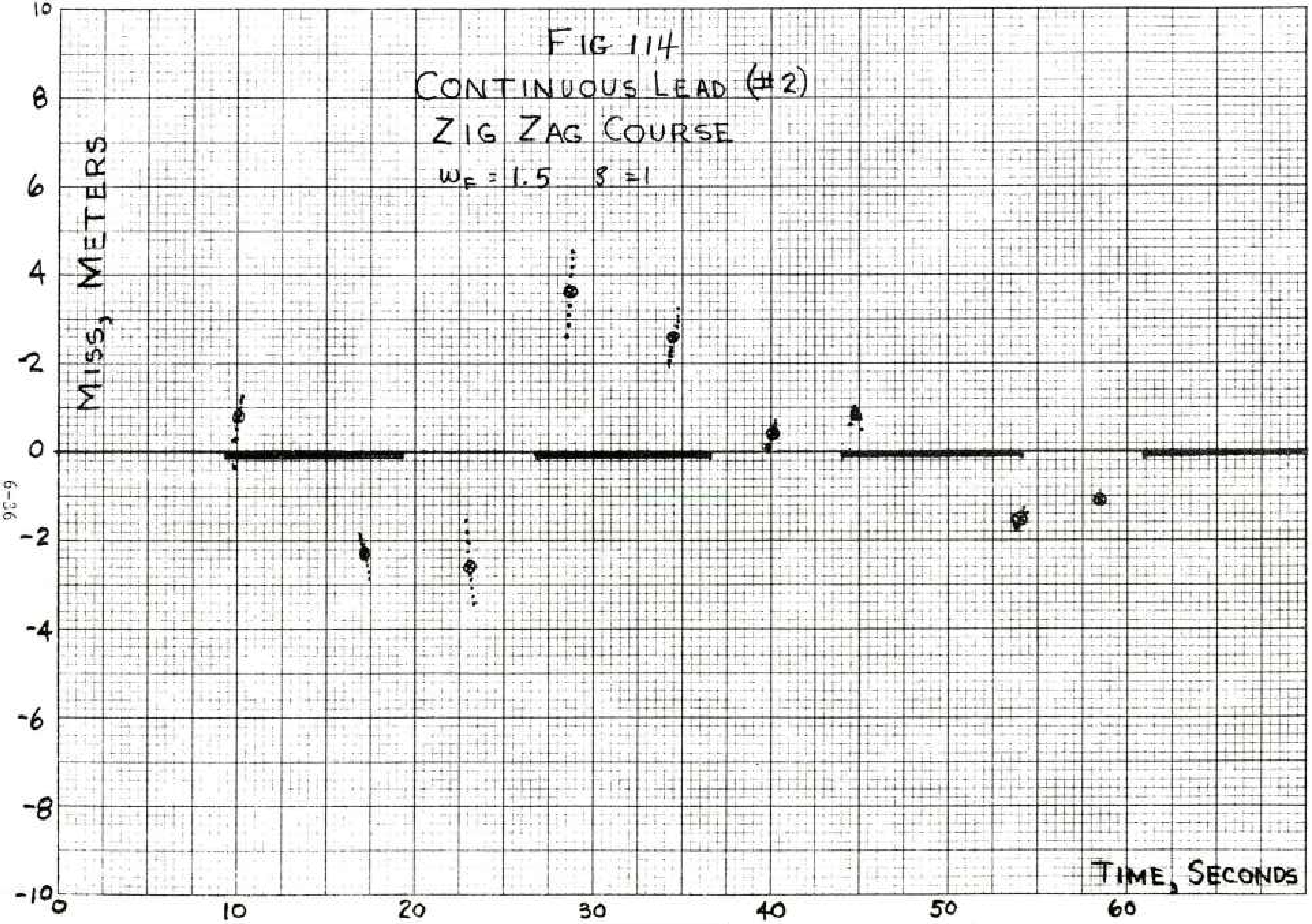


FIG 114
CONTINUOUS LEAD (#2)
ZIG ZAG COURSE
$\omega_F = 1.5 \quad \beta = 1$
MISS, METERS
TIME, SECONDS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60

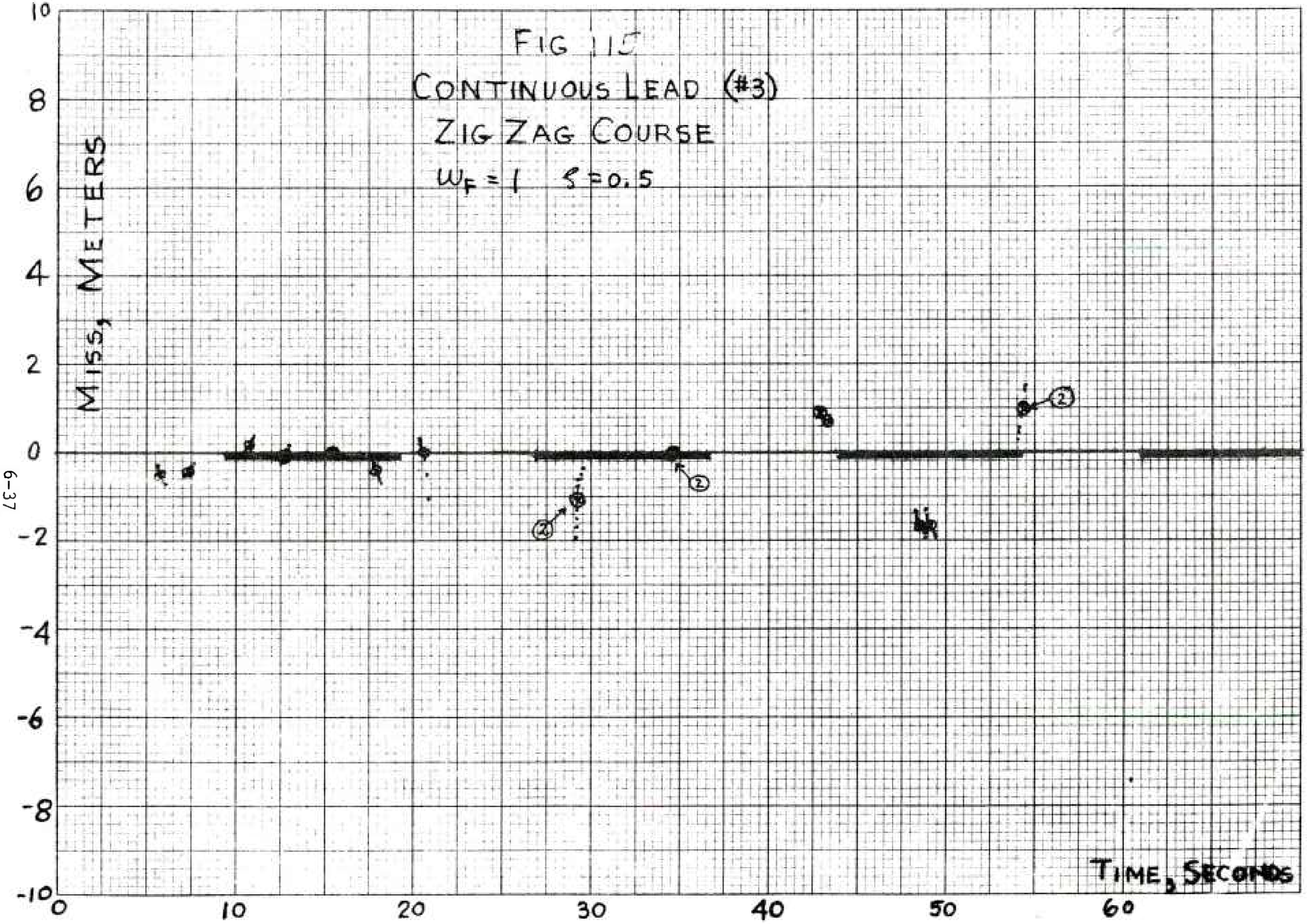


FIG 115
CONTINUOUS LEAD (#3)
ZIG ZAG COURSE
$\omega_F = 1$ $\zeta = 0.5$
MISS, METERS
TIME, SECONDS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
2

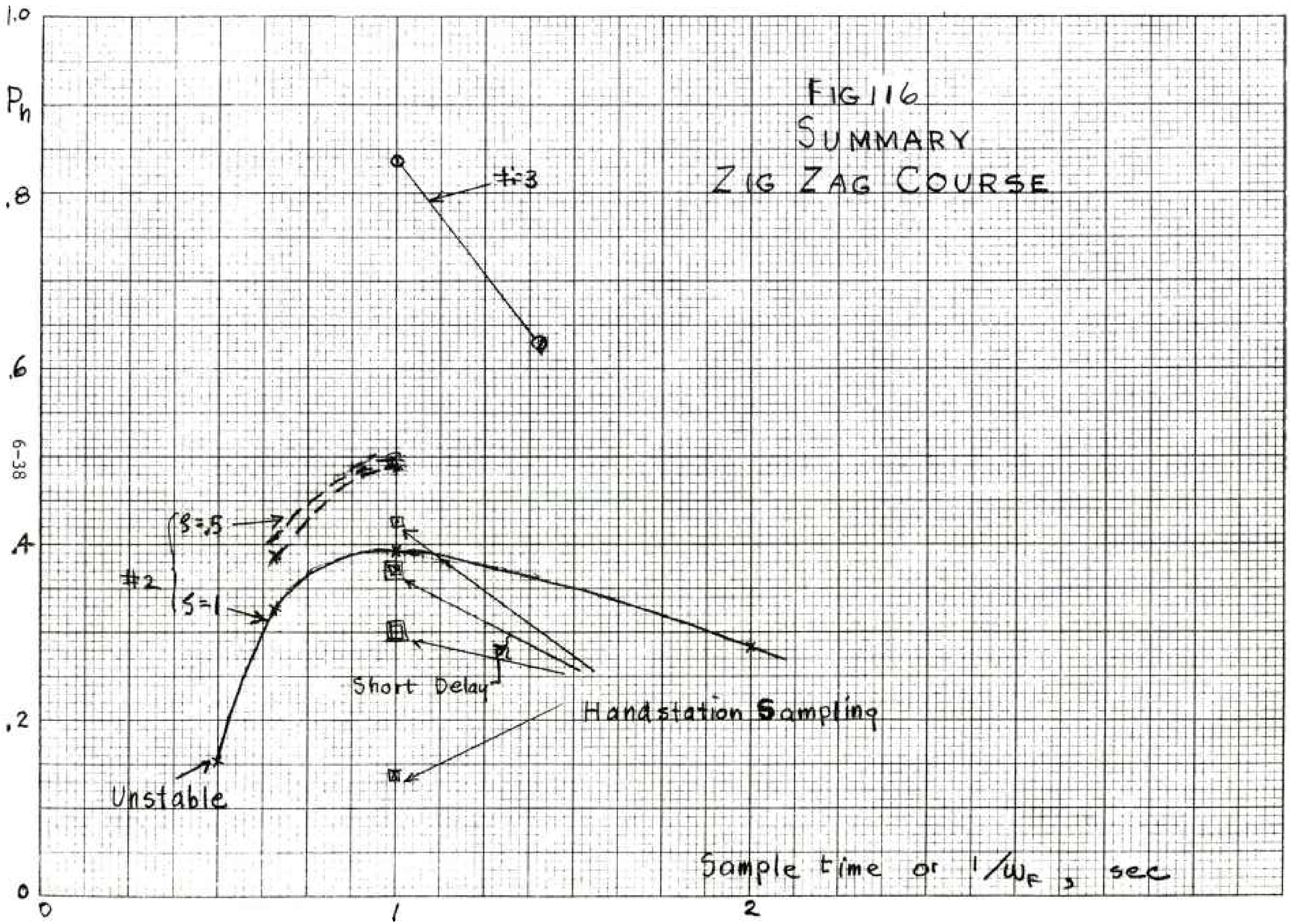


FIG 116
SUMMARY
ZIG ZAG COURSE
P_h
1.0
.8
.6
.4
.2
0
0
1
2
#3
#2
δ=.5
δ=1
Unstable
Short Delay
Handstation Sampling
Sample time or $1/\omega_F$, sec

a. Continuous lead generation without rate aiding is a little better than interrupted (sampled) lead generation. Continuous lead generation with rate aiding achieves a substantial improvement in performance.

b. Performance for the continuous lead systems is improved by decreasing the damping factor of the quadratic filter network from 1 to 0.5.

c. A natural frequency of about 1 rad/sec appears to be best for the filter network for the continuous systems. These results are for a smooth Zig-Zag course and are subject to review when simulated terrain roughness is added.

From the preceding, it is clear that rate aiding helps considerably. These results have been obtained for perfect instrumentation in which tracking rate due to own vehicle velocity normal to the LOS is assumed to be known exactly. It is important to determine how sensitive the performance results are to tolerances in the velocity instrumentation. These results are shown in Figure 117. It is seen that (below a SF = 1), P_h degrades quite rapidly with tachometer scale factor. However, for practical tolerances (a few percent) the rate aided system still achieves substantial advantages over the other systems.

Figures 118 through 121 address the case of simultaneous roughness and turns. Figure 118 shows the need for additional cant rate correction for these conditions. Changes of superelevation and deflection caused by changing vehicle target range or speed conditions feed directly into the gun servos (as previously shown in Figure 113) and are achieved without any gunner input. However, changes in these angles associated with a change in cant, although desirable to have as shown in Figure 118, were not instrumented in the XM-19 because cant could not be measured with the vehicle moving. However, with continuous lead angle generation, and with a stable vertical, it is desirable to instrument for all major own vehicle motions so that the gunner is required only to track target vehicle motion changes and small residual errors. Thus, a correction,

$$\text{Correction} = C \times \dot{R}$$

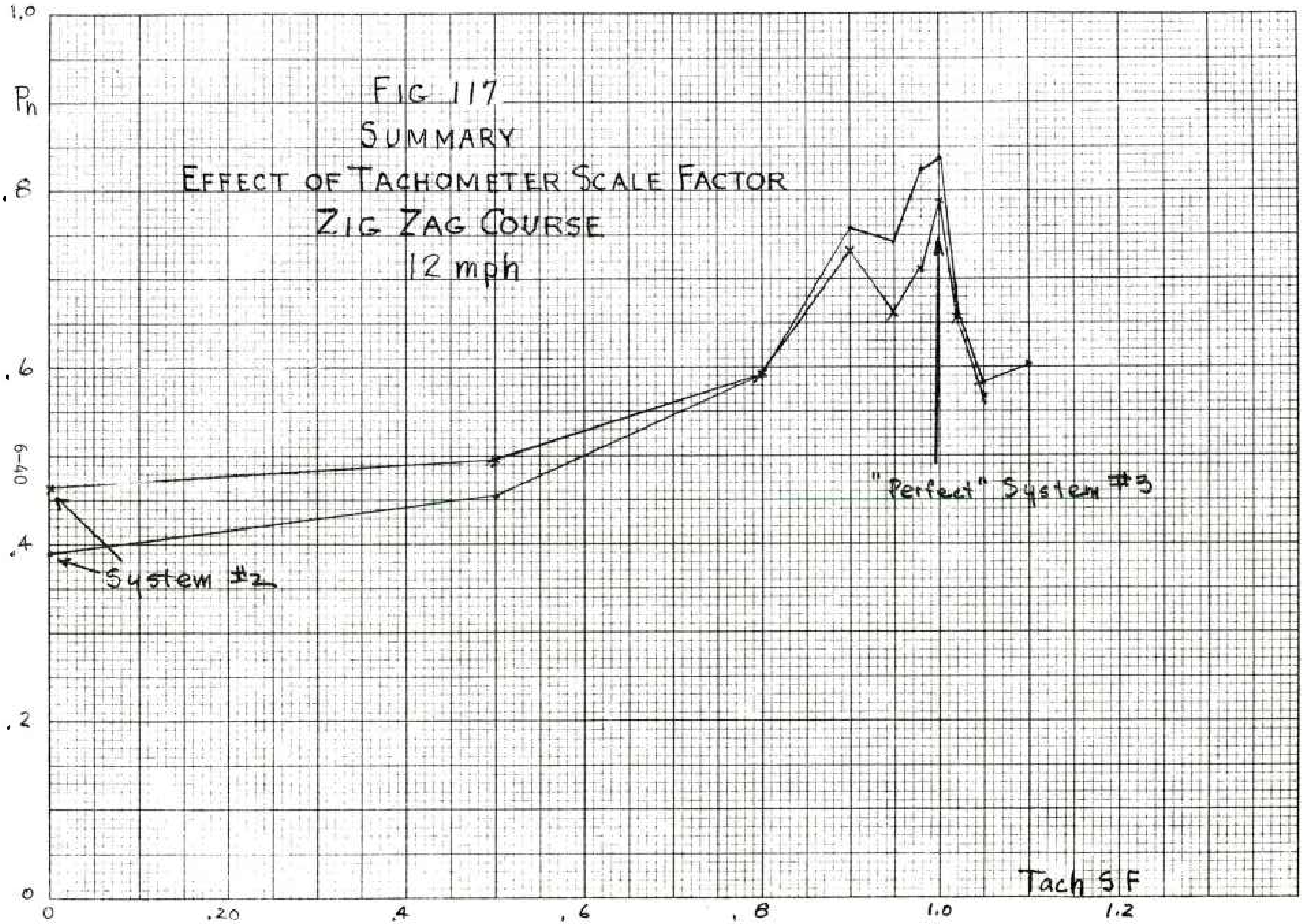


Fig 117
Summary
Effect of Tachometer Scale Factor
Zig Zag Course
12 mph
Pn
1.0
.8
.6
.4
.2
0
0
.20
.4
.6
.8
1.0
1.2
Tach SF
"Perfect" System #3
System #2

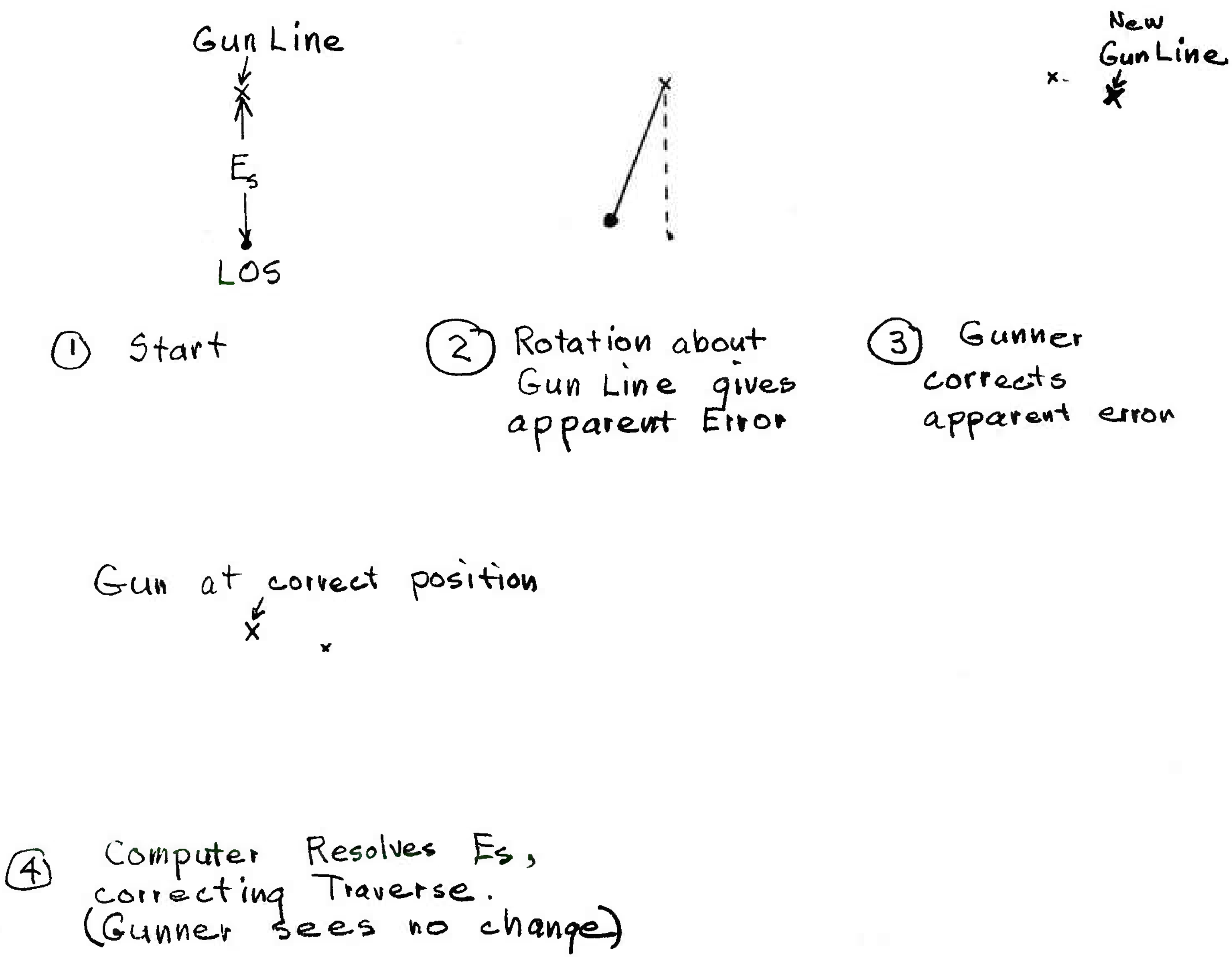


FIG 118

EFFECT OF ROTATION ABOUT LOS

was added to the instrumentation where $\dot{C}$ is cant rate and R is the resulting gun line -LOS offset = $\sqrt{E^2 + D^2}$.

Figure 120 is much like Figure 119 except that the regular APG bumps are used. In this case, cant has smaller amplitudes with higher rates, and errors are caused mostly by just plain jostling of the gun stabilization system. Thus, inclusion of cant rate correction shows much less advantage.

Figure 121 is a summary of a number of runs on two different systems over the Zig-Zag course with APG bumps. Some of the general conclusions that may be drawn from these results are:

a. There is a moderate improvement with longer sample time (longer smoothening time). This is the result of better smoothening of the effect of course roughness. However, since this improvement with smoothening is rather small, the smoothening time should be maintained on the low end of the range to allow better tracking of changing target motion.

b. The hand station sampling results are quite variable with condition. (This will be discussed more, subsequently).

c. The continuous lead shows considerable improvement over the sampling generation of lead. It is felt that the improvement is really more substantial than that indicated in Figure 121, as will be explained in the following discussion.

The interrupted lead results are quite dependent on chance conditions during the run. The combination of sharp turns in the course with bump-induced motions make the tracking job so difficult that the gunner is able to get off only four or five bursts during the run (compared with nine to ten for the continuous lead case). Generally, these shots miss badly, causing low hit probability. Occasionally, the gunner will achieve what might be called a "lucky hit" (actually burst of shots) and such a burst of high hit probability can increase the average for the entire run when the total number of bursts is relatively few.

In the case of continuous lead with aided tracking, the gunner is "on target" more of the time and is able to shoot more often. Most of these shots are quite close to the target, but the average hit probability score is hurt somewhat by the truth of the old adage, "a miss is as good as a mile."

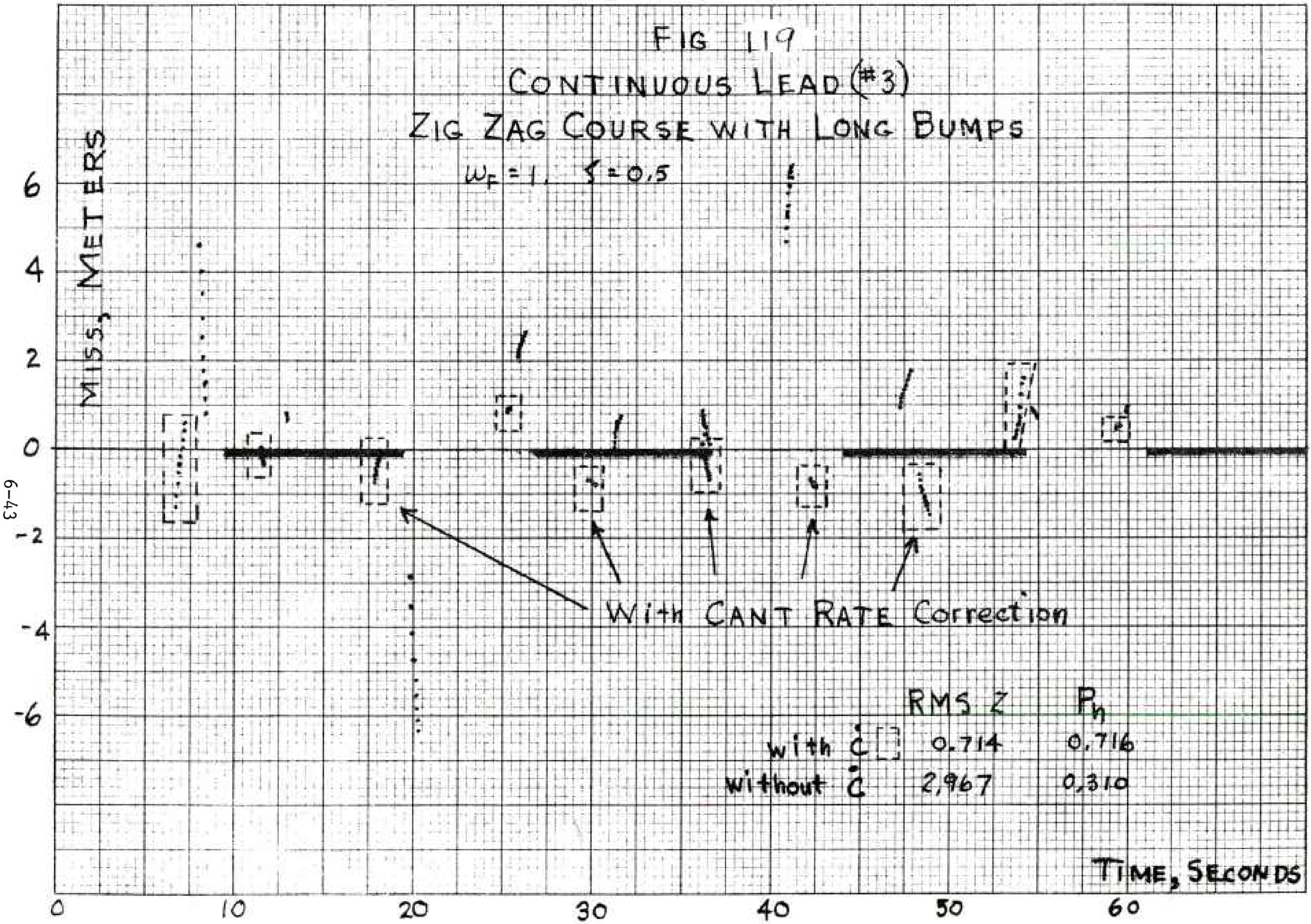


FIG 119
CONTINUOUS LEAD (#3)
ZIG ZAG COURSE WITH LONG BUMPS
$\omega_F = 1, \ \zeta = 0.5$
MISS, METERS
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
TIME, SECONDS
With CANT RATE Correction
RMS Z
P_h
with $\dot{C}$
0.714
0.716
without $\dot{C}$
2.967
0.310

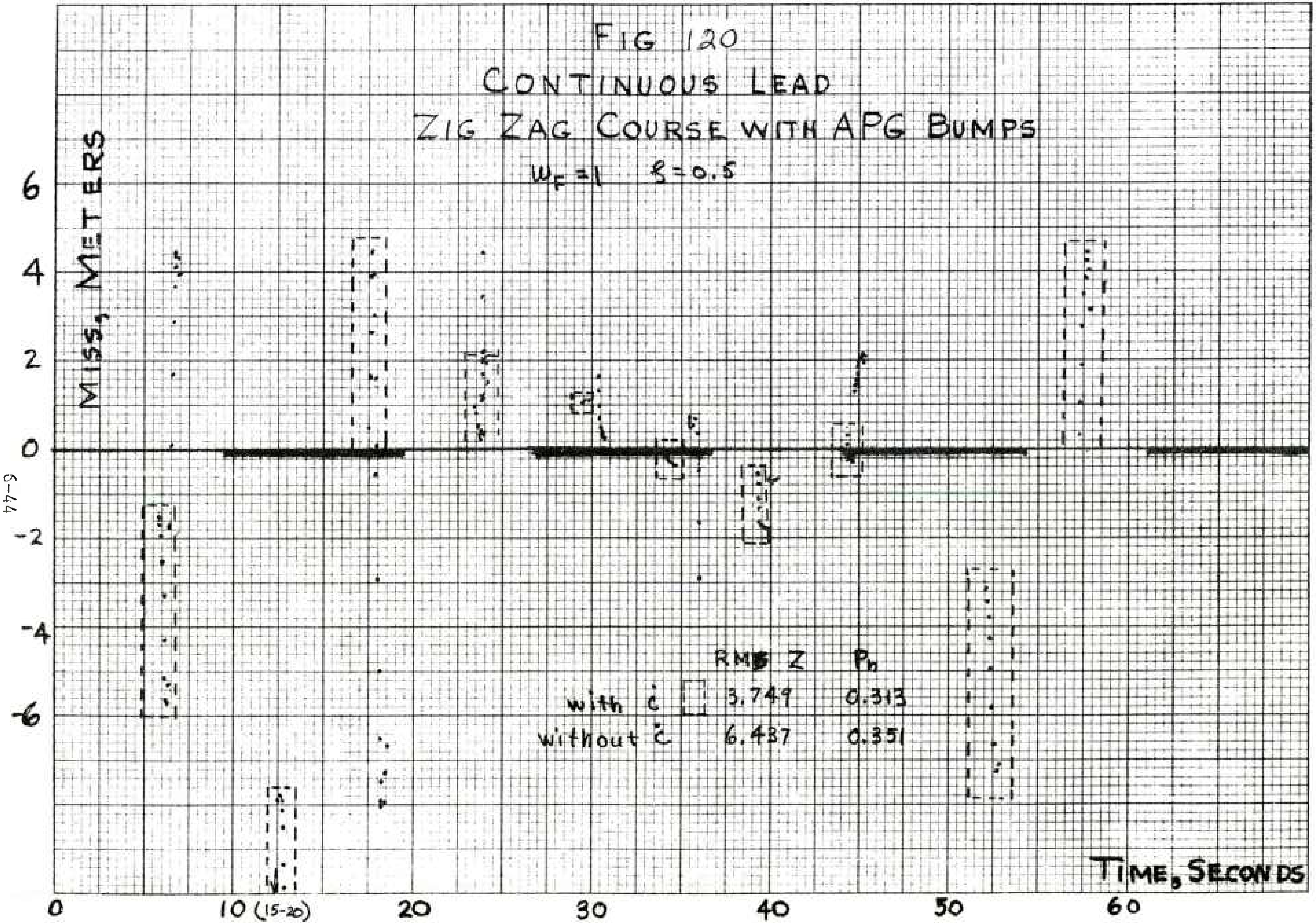


FIG 120
CONTINUOUS LEAD
ZIG ZAG COURSE WITH APG BUMPS
$w_F = 1$ $\xi = 0.5$
MISS, METERS
6
4
2
0
-2
-4
-6
RMS Z
P_h
with c
3.749
0.313
without c
6.437
0.351
0
10 (15-20)
20
30
40
50
60
TIME, SECONDS

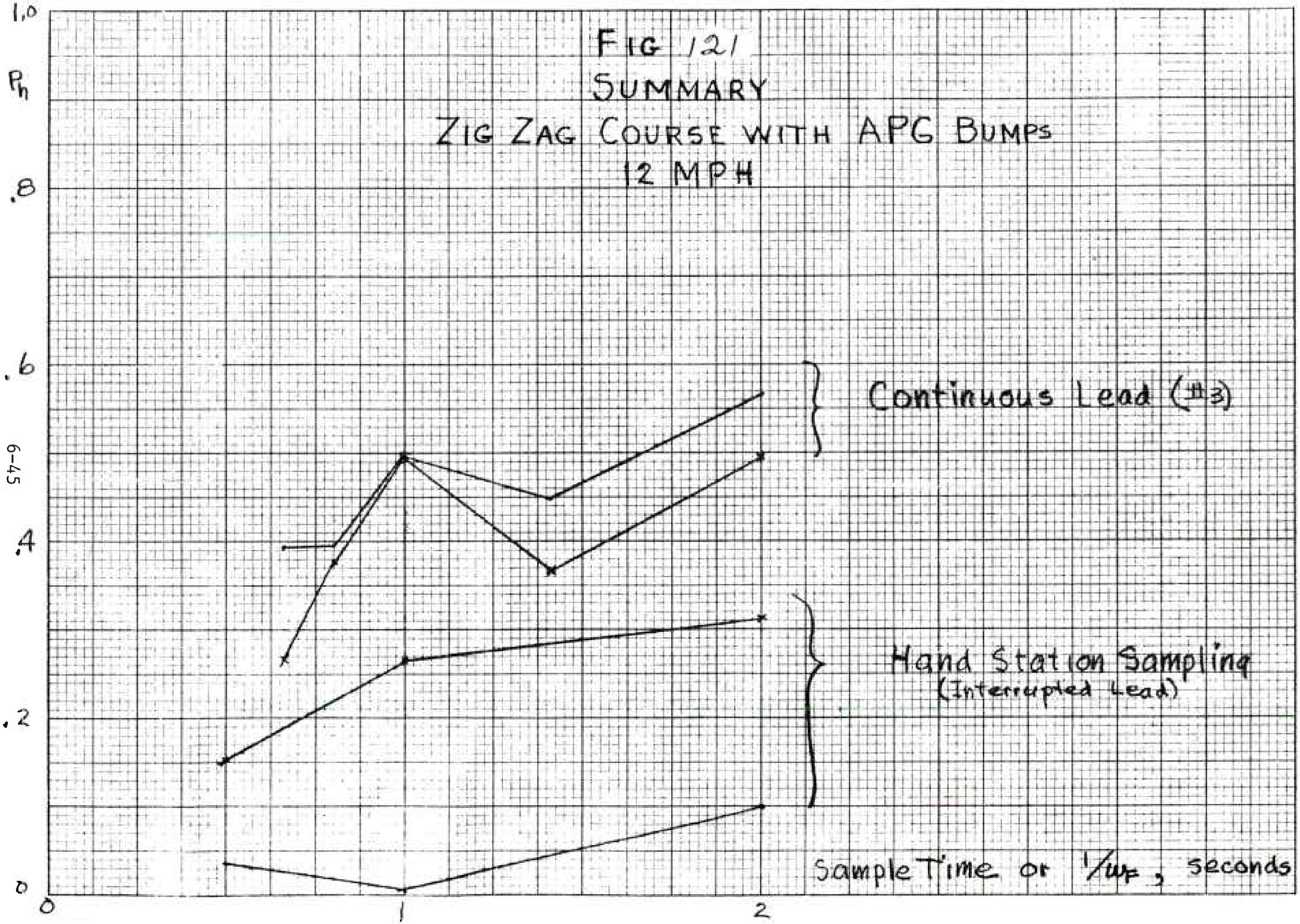


FIG 121
SUMMARY
ZIG ZAG COURSE WITH APG BUMPS
12 MPH
1.0
P_h
.8
.6
.4
.2
0
0
1
2
Continuous Lead (#3)
Hand Station Sampling
(Interrupted Lead)
Sample Time or $1/\omega_F$, seconds

6.3.3 Fire Control Improvements Selected for Test

The fire control system configurations selected include:

a. Continuous lead angle computation,

b. Rate aided lead computation and tracking, and

c. Hand station rate data for lead angle computation.

The basic system modification will include these features.

Army representatives at the 15/16 Jun 1971 meetings requested flexibility in the design so that signals could be selectively switched in or out. In addition, they requested that an interrupted lead computation mode be provided. As a result, it was agreed to provide modes and switching as summarized in Table 5.

The net result of the decisions and agreements reached at the 15/16 Jun 1971 meetings resulted in the proposed A1E2 modification, as illustrated by Figure 122. The changes made to this diagram since the 15/16 Jun 1971 meetings are the addition of the sample and hold circuit for the interrupted lead computation mode and the inclusion of the switching options.

The implementation of this system requires the addition of sensors and the modification of the XM-19 computer.

a. Add Sensors

Vertical Gyro

Tachometers for Velocity

Resolver for Velocity Resolution

b. Modify Computer

2 Range Potentiometers

2 Circuit Boards - Gunner's Control Unit

1 Circuit Board - Computer Unit

1 Electronics Module - Computer Unit

Preliminary effort was done to investigate the availability of the sensors which are long lead time components. Data on the vertical gyro is summarized on Table 6, with data on velocity sensing and resolution shown as Table 7.

TABLE 5 MODES OF MODIFIED FIRE CONTROL SYSTEM

				SWITCHING MODES			
				TRACKING AIDES			
Lead Computatian Mode	Track Source Hand Station	Record Stabilizatian Gyro	Integratian Circuit Time Constant	Vehicle Maneuver	CANT Rate	CANT Resolutian	VEHICLE VELOCITY (WIND)
Continuous	Yes	Yes	1 sec.	On/Off	On/Off	On/Off	On/Off
Interrupted	Yes (Note 1)	Yes	1 sec.	On/Off	On/Off	On/Off	On/Off

NOTE 1: Switching to provide an angular rate input from the gun stabilizatian traverse gyro will be provided if readily possible.

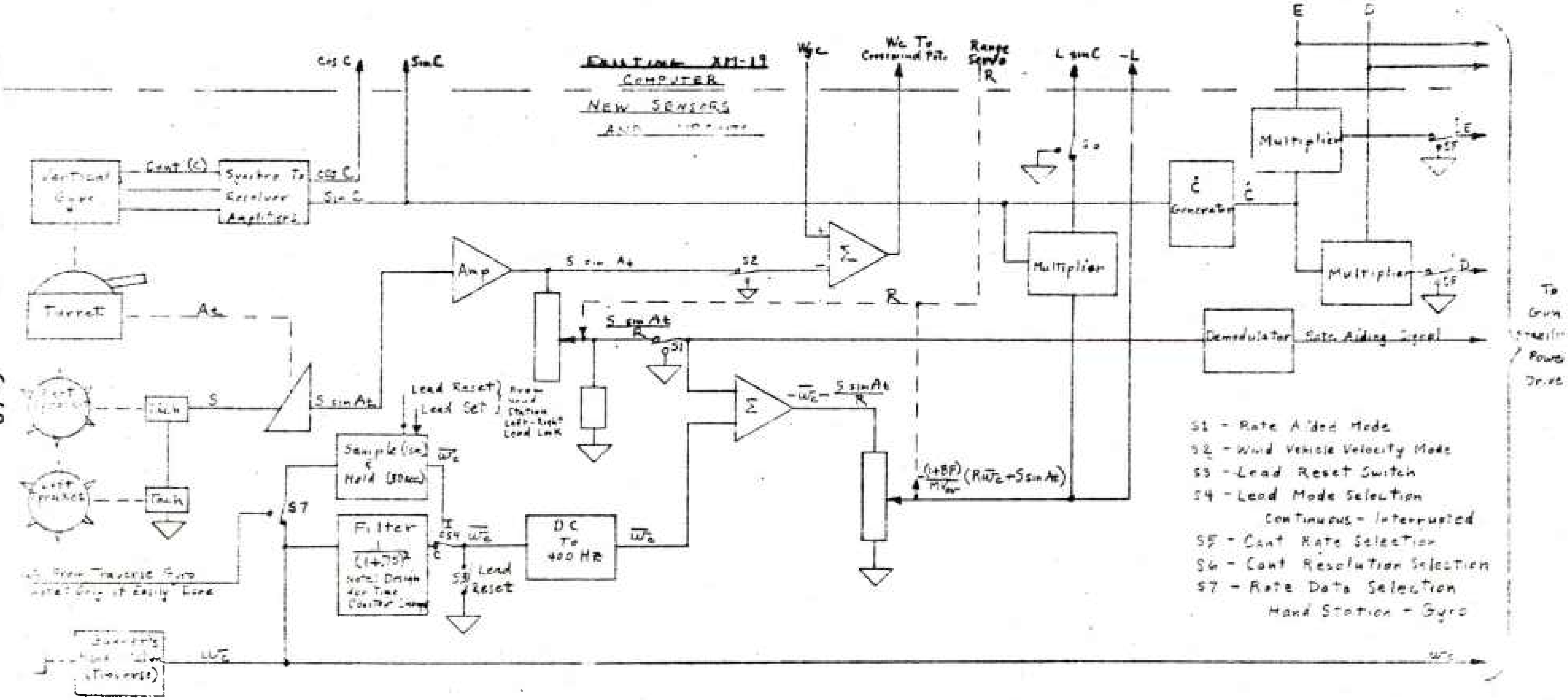


Figure 122 "Proposed A1E2 Modification"

TABLE 6 VERTICAL GYRO

Aircraft Type

Shock Mounted In Place Of CANT Unit

Power	115 V,	400 HZ
	Start	60 VA
	Run	30 VA

Synchro Output

Delivery 60 - 90 days

TABLE 7 VELOCITY SENSING AND RESOLUTION

Two Tachometers

Flexible Cables From Sprocket Wheels

Drive Tachometers Mounted On Fenders

Series Connection To Add Track Velocities

Power 115 V, 400 HZ, 11.4 VA

4 Turret Slip Rings Required

Precision Resolver

Modified Azimuth Indicator Drive For

Resolver Plus

Turret Train Instrumentation

The computer modification requires the addition of two new range servo potentiometers with the removal of one of the present potentiometers. This change can be made in the gunner's control unit. The basic continuous lead computation electronics will be packaged in the space formerly occupied by the two lead computation boards in the gunner's control unit. The vertical gyro associated electronics will be mounted in the spare circuit board slot in the computer unit. The sample and hold circuit electronics for the interrupted lead computation mode will be mounted as a module in place of the train gyro in the computer unit.

It appears that the present 115V, 400 Hz inverter can supply power for the modified computer and the added sensors. This is based on information provided that the inverter has a 150 VA capacity with the present computer requiring 75 VA, which includes 9 VA for the train rate gyro.

Ballistic data has been supplied to define the lead multiplication factor that must be generated by one of the new range potentiometers. Previous data on the effects of non-standard conditions on the XM409 round indicate the air density and muzzle velocity variations are significant and should be considered in a future system. The effects are summarized in Table 8.

TABLE 8 XM409 BALLISTIC VARIATIONS

Air Density		
	BF	13% for 10% in AD
	Q	3% for 10% in AD
Muzzle Velocity		
	All Terms In Equations	
	Q	4% for 40 Ft/Sec

6.4 NON-FIRING TEST RESULTS M60A1E2 DEMONSTRATION FIRE CONTROL SYSTEM

6.4.1 Background

Non-firing tests were performed on an M60A1E2 vehicle, equipped with a modified XM19 Ballistics Computer, at the GEOS Test Range at Pittsfield, Mass. These tests were run during late December 1971 and early January 1972. The December tests were performed with an experienced gunner, Mr. Richard Garrity, of Aberdeen Proving Ground (APG), and utilized motion picture coverage of the gun tube (Mantlet) and gunner sighting (Split Beam Camera) as well as Visicorder recording of approximately 20 channels of information. The January tests were performed with an inexperienced gunner and without the Split Beam Camera coverage. However, these later tests all utilized the XM19 modification which employs tracking rate aiding and which minimizes gunner tracking requirements.

a. Interrupted Lead Generation, Gun Rate Gyro Sampling versus Hand Station Sampling. (The first of these approximates the original XM19 implementation).

b. Interrupted Lead Generation versus Continuous Lead Generation.

c. Continuous Lead Generation, all gunner generated rate versus rate aiding implementation.

d. No Cant Correction versus Continuous Cant resolution. Several sub options within this general category may be exercised.

6.4.2 Summary of Test Results

a. For the Interrupted Lead Generation, Hand Station Sampling leads to definitely superior results as compared with Gun Gyro Sampling. This confirms simulation results which indicates that the gunner does not respond, therefore, "acts as a filter" to much of the vehicle motion-induced high frequency pointing errors of the gun. Thus, the Hand Station Signal gives a better indication of tracking rate for lead angle generation. The difference between the two sampling points is greatest for bump course runs toward the target when very low tracking rates are required. However, the Hand Station Sampling shows noticeable improvement even at moderate tracking rates.

b. The continuous lead generation did not show the expected accuracy advantage over the interrupted lead generation. On an accuracy comparison only, there was no clear choice between the two configurations. There are several reasons for this, all largely individual in nature:

(1) The experienced gunner, who performed on all the interrupted lead runs, was able to get on target quickly (typically 1½ to 2 seconds) after a lead reset. This allowed a "firing" before the lead requirements had changed greatly. (This is the large potential source of error for the interrupted lead system when operating on a changing course, such as a Zig-Zag course).

(2) The gunner was also quite responsive in continuous tracking, thus outputting a relatively rough hand station signal that was not well enough filtered by the low pass filter in the lead generation channel. Average gunners are expected to react more slowly.

(3) There is an inherent compromise in the selection of the bandwidth of the above-mentioned low pass filter. The bandwidth should be high to allow rapid setting to the required lead angle. On the other hand, the bandwidth should be low to more effectively smooth the gunner tracking signal.

On an overall performance basis, the continuous lead did show an advantage as it allowed the gunner to make about twice as many "shots" during the run as the interrupted lead system.

c. The rate-aided system was considerably better than the system without rate aiding. The generated lead angle was consistently smoother and closer to the theoretically-correct answer. In addition to generating more accurate lead angles, the tracking effort imposed on the gunner is greatly reduced.

d. The continuous Cant Correction is necessary. Even for the GE Test Courses, which were laid out on relatively level terrain, Cant angles of several degrees were frequently encountered. For some of the longer ranges, this can result in a deflection angle error of 1 mil or more unless corrected. The tests indicated that the experimental equipment provided this correction accurately.

APPENDIX A

HITPRO UPDATED

A.1 Revised Recoil Subroutine

A.1.1 Listing of Revised Recoil Subroutine

Figure A-1 is a revised recoil subroutine for the HITPRO II mathematical model as reported in HITPRO II, Volume II, DDC # AD917763. This revision was necessary to model automatic cannon type weapons having much slower firing rates than the 20 mm Hispana Suiza gun which was originally modeled. The modifications also allow the modeling of cannon type guns having soft or constant recoil.

A.1.2 Explanation of FORTRAN Statements Used in Figure A-1

Statement	Function
5	KO(17) is a switch (0 or 1). Once KO(17) is turned on in statement 11, statements 18 through 32 are executed until KO(17) is turned off (set to 0) in statement # 33.
6	KO(8) is the firing switch KO(8)=1 to fire (set in GUNNER).
7	NRD = + if the recoil force and distance data is for a multi-shot burst, 0 or - if for a single shot.
8	KO(31) is a counter of shots in a burst. Note that KO(18) is used in other subroutines for this purpose, however, KO(18) does not get turned back to zero soon enough for the intended purpose here.
9	Statement 9 is a check to determine if a time delay has occurred since completion of the previous shot in a burst. Such time delays have occurred, but the author does not know why.
10	This statement assures that each shot (or each burst) starts on the same part of the integration cycle in order to obtain consistent recoil responses.

```
FORTRAN IV G LEVEL  21               MAIN              DATE = 76021         10/37/25              PAGE 0001

                 CRECOIL    GENERALIZED TIME BASED RECOIL WITH BURST OPTION
                 C
                 C          NRD=+ IF RECOIL FORCE (RC) AND RECOIL DISTANCE (RD) ARE FOR
                 C          FOR A MULTISHOT BURST, NRD=- OR 0 FOR SINGLE SHOT DATA
                 C          COMPLETELY REVISED BY L. D. WELLS  21 MAY 1974
                 C
                      SUBROUTINE RECOIL
                      IMPLICIT REAL*8(A-H,O-Z)
                      COMMON T,D,TS,Y,Z,V,C,CG,C5,CT,CW,CB,CP,CH,ZS,RC,RD,TRC,ZERO,NT,
                     1NW,KB,KO,N1,N2,N3,NRC,NRD
                      DIMENSION Y(90),Z(90),V(400),C(96),CG(96),CS(40),CT(40),CW(56),CB(
                     173),KB(78),KO(32),CP(96),CH(20),ZS(90),RC(200),RD(200),TRC(210)
                      IF(KO(17)) 5,5,50
                    5 IF(KO(8)) 100,100,10
                   10 IF(NRD) 25,25,15
                   15 IF(KO(31)) 25,25,20
                   20 IF(T-TF-TR-0.5001*D) 30,30,25
                   25 IF(N1-1) 100,100,30
                   30 KO(17)=1
                      IF(KO(31)) 45,45,35
                   35 IF(NRD) 45,45,40
                   40 IF(T-TF-TR-0.5001*D) 50,50,45
                   45 I=1
                      K=1
                      TF=T
                   50 TR=T-TF
                      IF(I+1-NRC) 55,55,85
                   55 IF(TR-TRC(I+11)) 65,65,60
                   60 I=I+1
                      IF(I+1-NRC) 55,55,70
                   65 V(184)=RC(I)+(RC(I+1)-RC(I))*(TR-TRC(I+10))/(TRC(I+11)-TRC(I+10))
                      DIST=RD(I)+(RD(I+1)-RD(I))*(TR-TRC(I+10))/(TRC(I+11)-TRC(I+10))
                      GO TO 75
                   70 V(184)=ZERO
                      V(187)=ZERO
                      GO TO 80
                   75 V(187)=-V(125)*DIST*CG(63)
                   80 V(185)=V(187)-CG(71)*V(184)
                      V(186)=CG(72)*V(184)
                   85 IF(TR+1.0D-06-TRC(K)) 100,100,90
                   90 KO(17)=0
                      K=K+1
                      KO(31)=KO(31)+1
                      IF(KO(31)-KO(7)) 100,95,95
                   95 KO(31)=0
                      V(184)=ZERO
                      V(185)=ZERO
                      V(186)=ZERO
                      V(187)=ZERO
                  100 RETURN
                      END
```

Figure A-1 Listing of Revised Recoil Subroutine

Statement	Function
11	KO(17) turned on - the beginning of a new recoil cycle.
12	This is a check to determine if this is the beginning of a burst.
13	A data check as in statement 7.
14	A time delay check as explained before.
15-17	A new burst has started - initialize variables.
18	TR is the time during recoil relative to the start of the burst.
19	This is a check to determine if all of the input data has been used already. If so, zero is assumed for the remaining time.
20-24	Interpolate recoil force V(184) and recoil distance (DIST). Note that recoil force pushing backward on the vehicle is negative. Also rearward displacement is negative. Recoil distance is the movement of the gun recoiling mass.
26-27	These statements are used if all the input data has been used and there is additional time left in the recoil cycle which is a dead time before the next shot.
29	Note that CG(63) is now the mass of the recoiling parts (slugs) and CG(65-70) are not used.
30-31	Compute recoil torques as in standard HITPRO II.
32	This statement determines when a cycle is over. TRC(K) is the time when the K'th shot in a burst is finished. $(1 \leq K \leq 10)$
33-35	Set up counters for next shot.
36	This statement determines if a burst of KO(7) rounds has been fired.
37-41	These statements reset KO(31) and assure that all recoil forces and torques are turned off.

A.2 Corrections MOTION and FIRST Subroutines

Two small errors have been discovered in HITPRO. In both cases the discovery was quite by accident and not through any unusual results obtained from HITPRO. In fact the two errors remained hidden because they did not cause sufficient effect on results to be noticed in validation checks. It is possible that the effect would be more noticeable on vehicles of radically different design than the M60 and MICV, which have been used in HITPRO studies to date.

A.2.1 Correction in Subroutine MOTION

Subroutine MOTION, page 2-30 in both DDC #AD917763 HITPRO II, Vol. II and DDC #891400 HITPRO, Vol. II, fifth statement from the bottom of the page (the first continuation statement for Y (11)) should read:

```
1 V(161) * V(163))/CT(25) - Y(18) * V(195)
```

That is, V(163) should be used instead of V(160).

A few comparison runs have been made with HITPRO using first V(160) and then V(163). In these runs, the vehicle motion was the same to within less than 1/2 of 1% during about 97% of the running time. During the remaining 3% of the time vehicle motion was different by yp to 1%.

A.2.2 Correction in Subroutine FIRST

Subroutine FIRST, page 2-16 in both HITPRO II, Vol. II and HITPRO, Vol. II, the ninth FORTRAN statement identified as JZ XFR should omit the V(2) after the = sign. That is, the corrected statement should read:

```
V(3) = (CT(1)*(CT(28) - CT(9))**2 + CT(5)* CT(28)**2)/32.2
```

In the existing FIRST calculations, the overall M60 pitch inertia is about 6.5% high. (Yaw Inertia is also high but yaw inertia plays a relatively minor roll in HITPRO responses). This means that the pitch suspension natural frequency would be 3.2% low and this is beyond the resolution of the usual validation measurements, particularly when the uncertainties in torsion bar characteristics are considered.

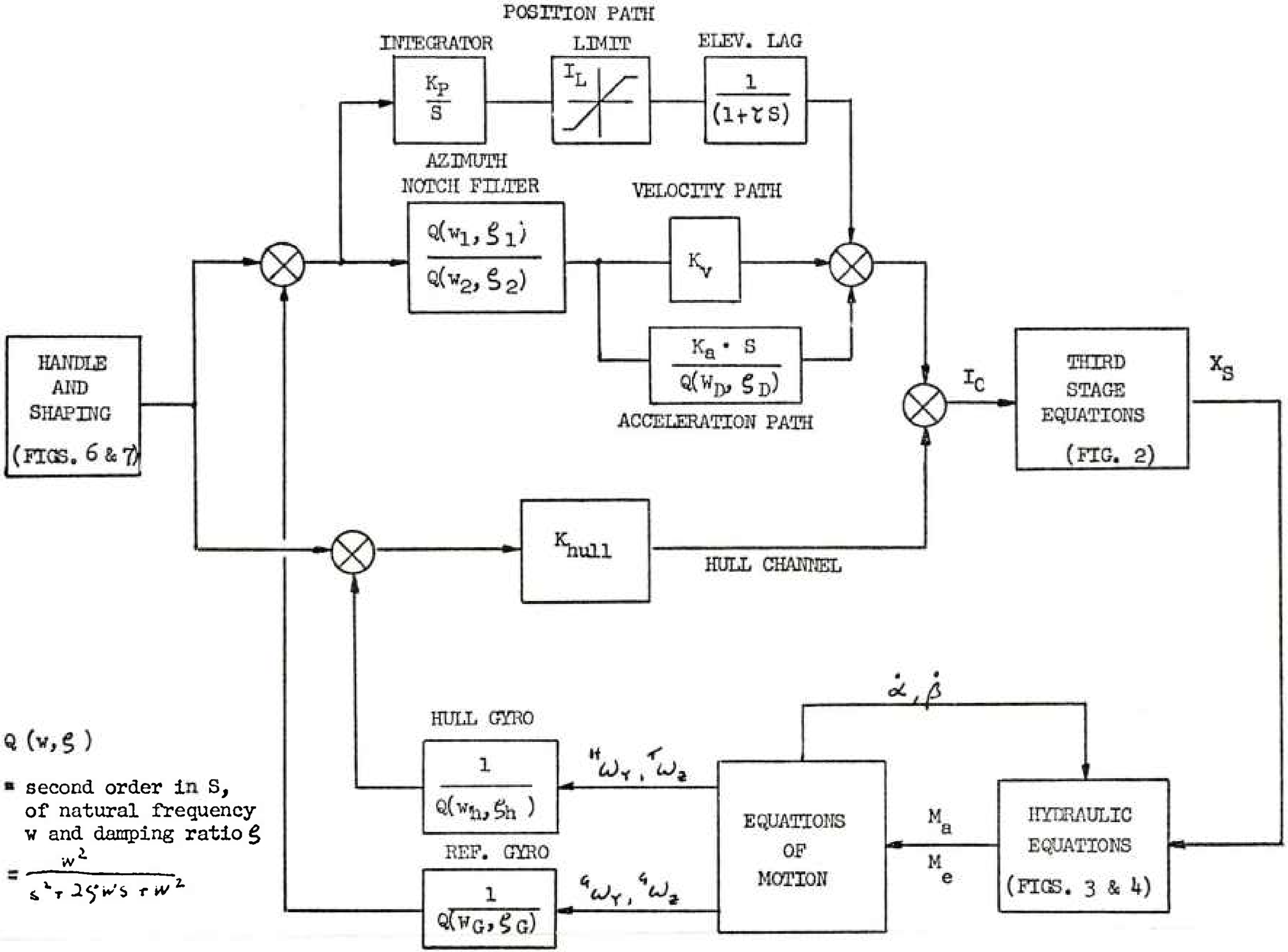
A.3 Electro-Hydraulic Control System Model

A.3.1 Introduction

A new DRIVE subroutine was written to simulate the standard M60A2 stabilization and gun drives in the HITPRO computer simulation. This stabilization system, designed by Cadillac-Gage and manufactured by Chrysler, is an electrohydraulic system with four gyros. Two gyros are mounted on the gun, one in the hull and one in the turret. The hull and turret gyro outputs are compared with rates commanded by the gunner and the difference is amplified to drive the gun in an open loop. This technique reduces the gain required for the closed loop portion of the system.

The electrohydraulic stabilization system is described in a Chrysler Defense Engineering Report #CDE 6231-50. This document was the basis for modeling the stabilization system. It furnishes block diagrams of the stabilization system in both elevation and azimuth, supplies parameters used in the systems, and describes non-linearities such as gunners control handle response and motor actuator response. This description is quite detailed and this is reflected in the model. Only the servo value (3rd stage closed loop) was simplified since it was found to have little effect on system behavior. The loop can easily be added to the model if desired as will be discussed below. The block diagrams for the electrohydraulic stabilization system modeled were taken from the previously-cited Chrysler report. These diagrams are shown in Figure A2-A6. The elevation and azimuth systems are very similar (except for parameters). In this computer model, a single system is modeled which represents either the azimuth or elevation control system, depending on the parameters used. This routine was written to be compatible with the existing HITPRO computer simulation and utilizes the second order Runge-Kutta integration routine in HITPRO to solve the differential equations. The DRIVE subroutine obtains inputs from other subroutines and the integration routine in the same way. The procedure for modeling linear systems in HITPRO is explained in HITPRO, Volume II (User's Manual) AD891400L RE-TR-71-63.

Many of the simplifications made in the G.E. version of the HITPRO DRIVE subroutine were not made in modeling the electrohydraulic system because it was felt that the component natural frequencies were in or near the range of frequencies that the weapon will experience. Therefore, for example, the gyros were not treated as perfect gyros.



$Q(w, \xi)$

= second order in S, of natural frequency w and damping ratio ξ

$$= \frac{w^2}{s^2 + 2\xi w s + w^2}$$

Figure A-2 Azimuth and Elevation Control Systems Block Diagram

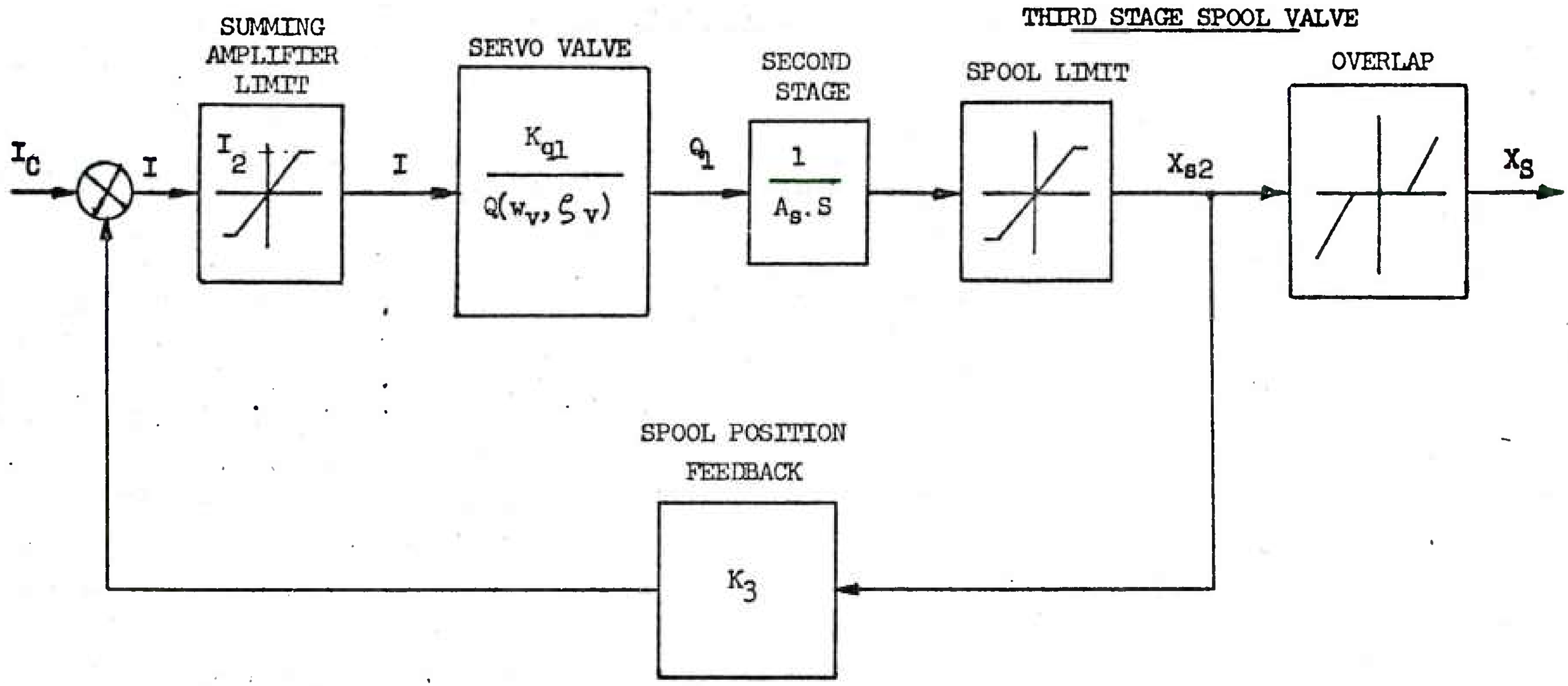


Figure A-3 Third Stage Closed Loop Representation, Azimuth and Elevation

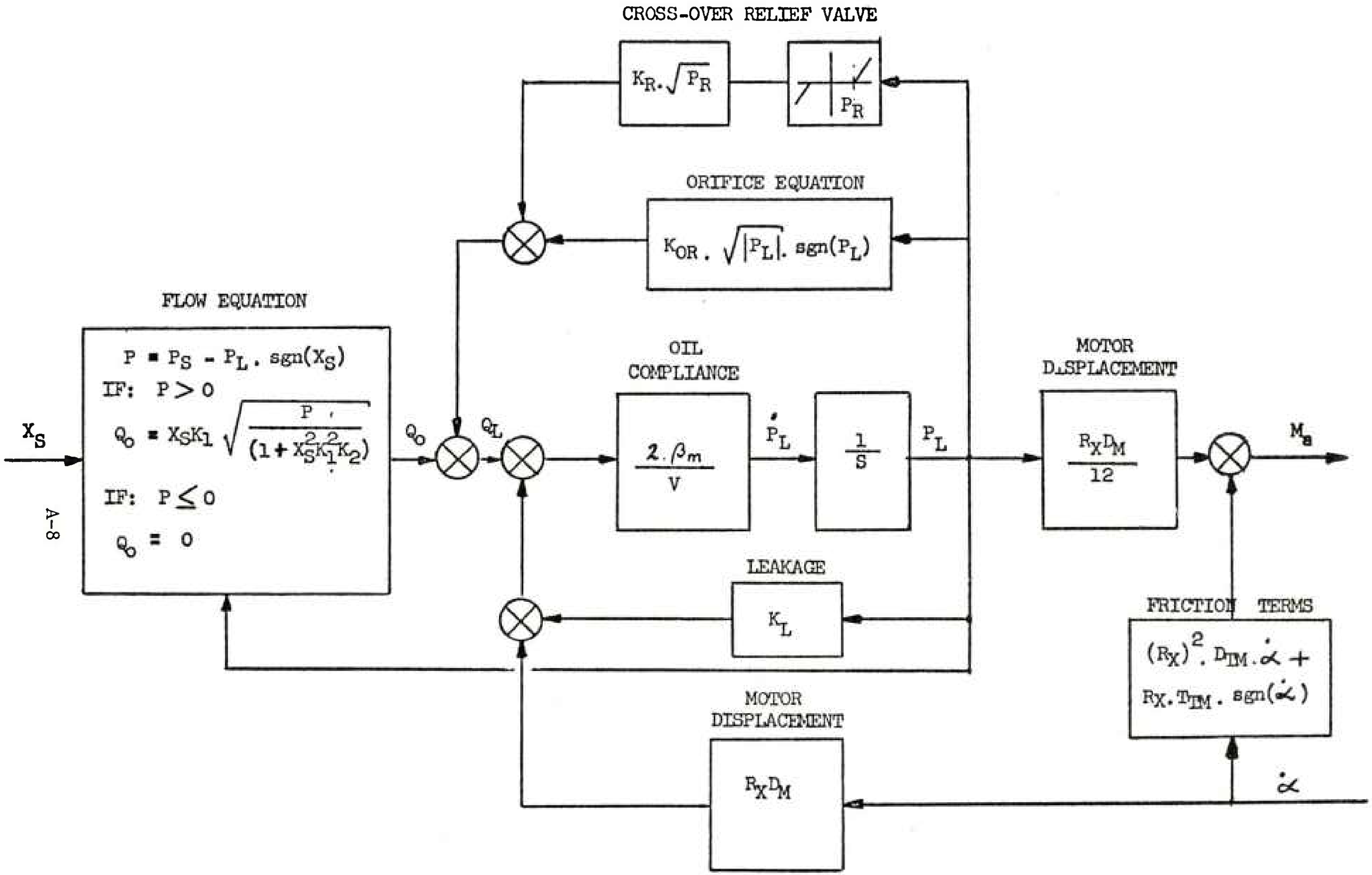


Figure A-4 Azimuth Hydraulic Motor Representation

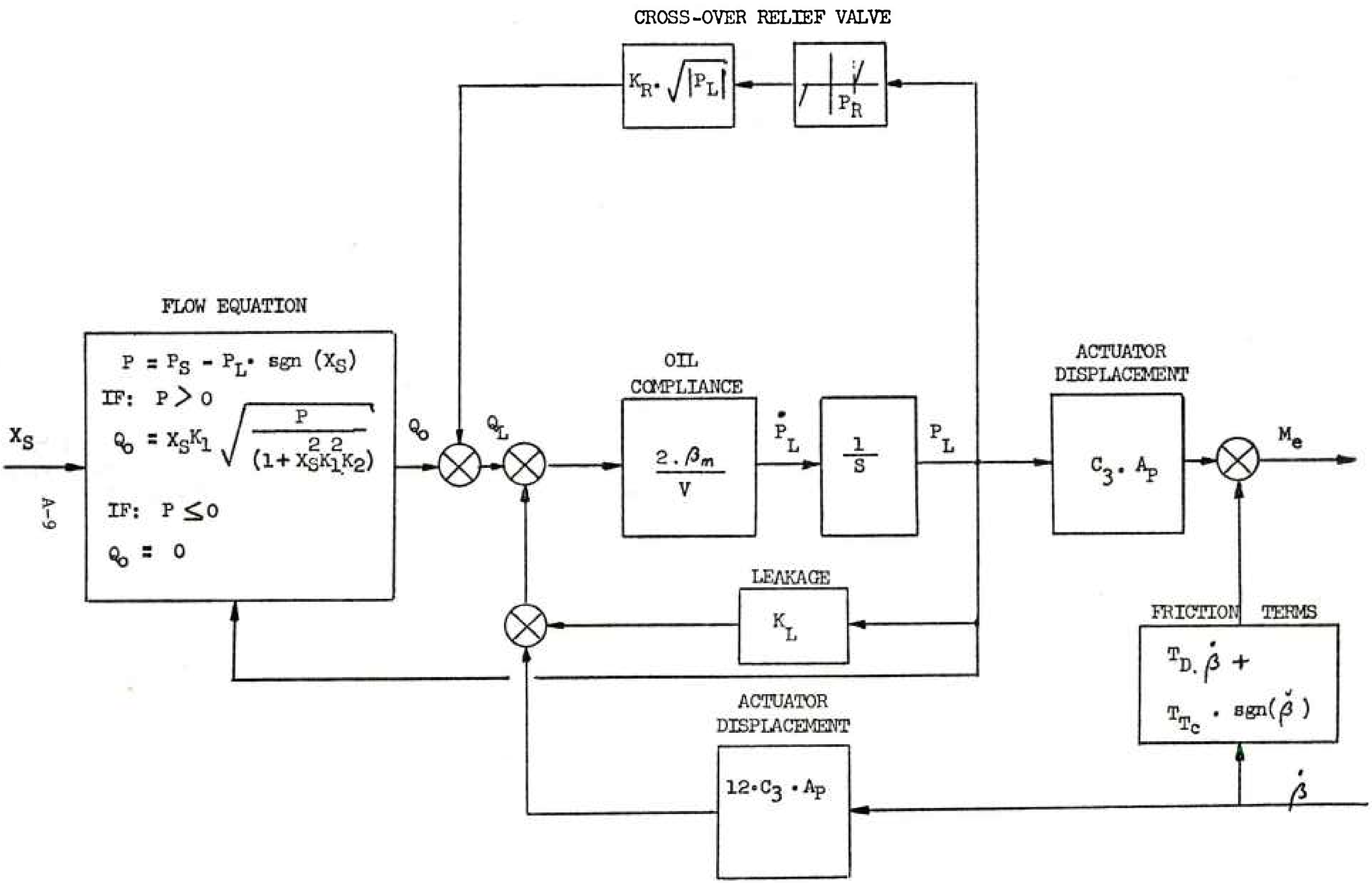


Figure A-5 Elevation Hydraulic Actuator Representation

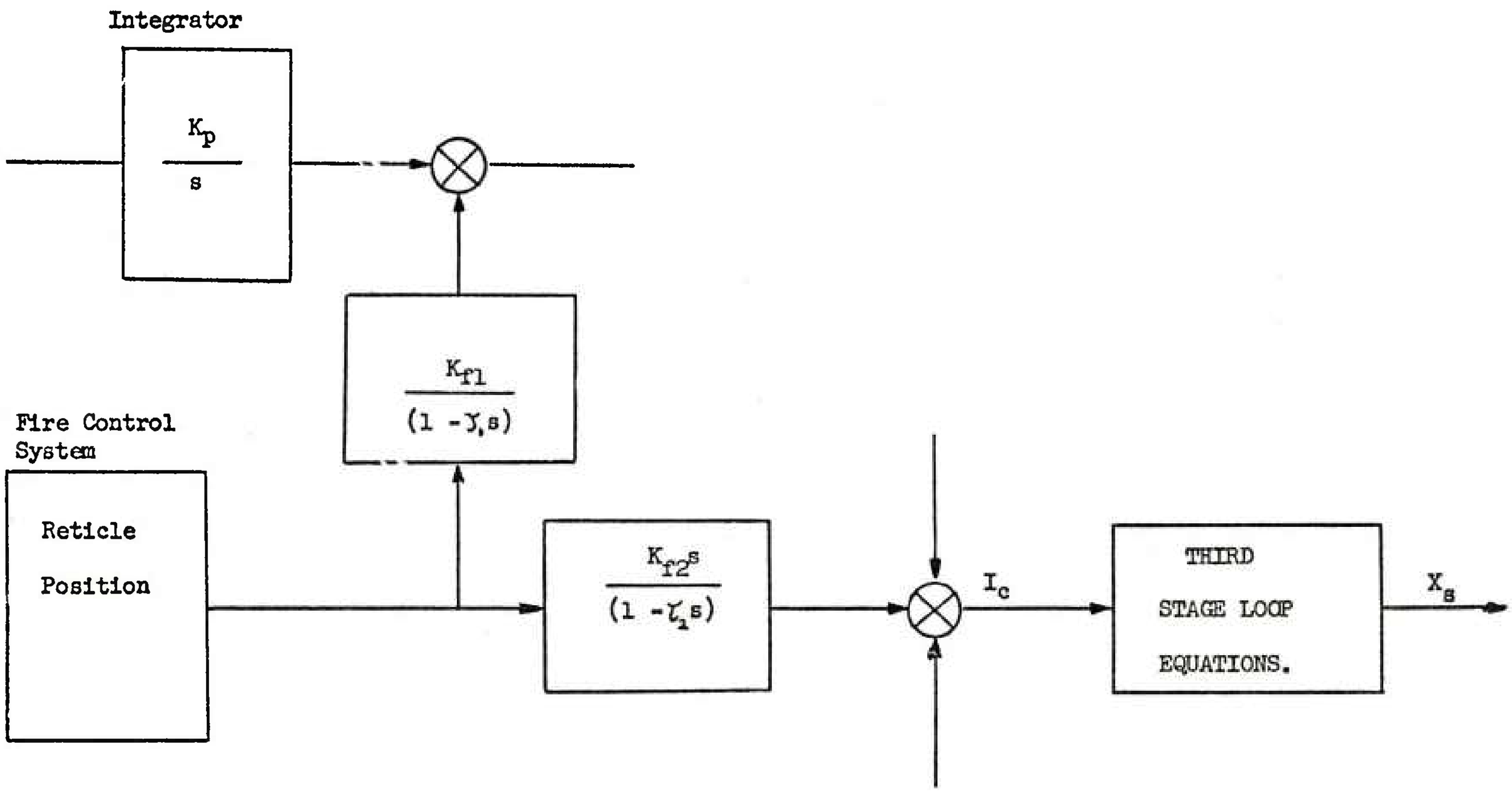


Figure A-6 Fire Control System Inputs and Filters
(Superelevation & Superlead)

A.3.2 Changes to HITPRO and HITPRO Input Data, Required by the New DRIVE Subroutine

Only a few changes to the HITPRO were made to accomodate the new stabilization system model. A new array Q was created and dimensioned to 99. This array was used for variables internal to the new DRIVE subroutine. This ensured that variables would not be reset accidentally in other subroutines.

Since the new subroutine contained more state variables than that previously modeled, the dimension of the arrays Z, Y, and ZS, used in the HITPRO integration procedure was increased to 90. These changes to the Dimension and Block Common Statements must be made in each HITPRO Subroutine. In the MAIN program, the array Q is zeroed, and several integrators are bypassed in the integration procedure. This is because several state variables in the acceleration path differentiator required very small integration time increments. To use the smaller time increment in all integrations would result in excessive run times. In the input data the number of DRIVE subroutine parameters, NC, is increased to 121. The number of integrators, NI, is increased to 90. New DRIVE parameters are used and the integration time increment is set at .005 which is the largest value giving good convergence with the new DRIVE subroutine. Some new variables (V(I), I 100) are defined in several subroutines but are only used for data output and they have no effect on the simulation.

A.3.3 Description of Computer Coding for Subroutine DRIVE

Statements 3-5 are identical in all HITPRO subroutines and the main program. Statement 3 defines all floating-point variables to be double-precision. All calculations involving these variables are double precision. This is the normal mode of operation for HITPRO on IBM 360 machines. Statement 4 defines the variable in Block Common between all HITPRO routines. The array Q in this common statement is unique to the electrohydraulic Cadillac-Gage stabilization system model. Statement 5 dimensions all arrays in HITPRO. The array Q is dimensioned 99, the arrays Z, ZS, and Y are dimensioned 90. Statement 6 defines a named common block that is shared only by subroutines DRIVE and DERIDE.

Statements 7-12 define some internal constants the first time through the subroutine. IVARY is the number of locations in the array Q used in

```
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,XREF
                C
ISN 0002              SUBROUTINE DRIVE
ISN 0003              IMPLICIT REAL*8(A-H,O-Z)
ISN 0004              COMMON T,D,TS,Y,Z,V,C,CG,CS,CT,CW,CB,CP,CH,ZS,Q,NT,NW,KB,KO,N1,N2,00118900
                     $ N3                                                           00119000
ISN 0005              DIMENSION Y(90),Z(90),V(400),C(150),CG(96),CS(40),CT(40),CW(56),  00119100
                     1CH(78),KB(78),KO(32),CP(800),CH(50),ZS(90),TITLE(20),Q(99)   00119200
ISN 0006              COMMON/TEMP/DT,I,K,L
ISN 0007              IF(KO(19)) 275,275,276                                        00119400
ISN 0008          275 KO(19)=1                                                      00119500
ISN 0009              IVARY=43                                                      00119600
ISN 0010              DT=0                                                          00119800
ISN 0011              TEST=.0000001                                                 00119900
ISN 0012          276 CONTINUE                                                      00121200
                C COMPUTE TURRET VELOCITIES AND ACCELERATIONS IN TURRET COORDINATES AS
                C IN ORIGINAL DRIVE SUBROUTINE
ISN 0013              V(146)=DCOS(Z(24))                                            00121400
ISN 0014              V(147)=DSIN(Z(24))                                            00121500
ISN 0015              V(148)=DCOS(Z(23))                                            00121600
ISN 0016              V(149)=DSIN(Z(23))                                            00121700
ISN 0017              V(21)=V(161)*V(147)+V(163)*V(146)                             00121800
ISN 0018              V(22)=V(161)*V(146)-V(163)*V(147)                             00121900
ISN 0019              V(332)=V(22)                                                  00122000
ISN 0020              V(23)=V(158)*V(147)+V(160)*V(146)                             00122100
ISN 0021              V(223)=V(23)                                                  00122200
ISN 0022              V(24)=V(158)*V(146)-V(160)*V(147)                             00122300
ISN 0023              V(125)=V(156)+CT(14)*V( 23)                                   00122400
                C                                                                   00122500
ISN 0024              V(27)=V(155)*V(146)-V(157)*V(147)-V(23)*CT(29)                00122600
ISN 0025              V(28)=V(157)*V(146)+V(155)*V(147)+V(24)*CT(29)                00122700
ISN 0026              CALL RECOIL                                                   00122800
                C DEFINE INPUTS FOOM OTHER SUBROUTINES
ISN 0027              Q(1)=V(162)                                                   00122900
ISN 0028              Q(2)=V(114)+V(162)                                            00123000
ISN 0029              Q(5)=V(152)                                                   00123100
ISN 0030              Q(8)=-V(330)*1000.                                            00123200
ISN 0031              Q(37)=V(114)                                                  00123300
ISN 0032              Q(1+IVARY)=V(21)                                              00123500
ISN 0033              Q(2+IVARY)=V(113)+V(21)                                       00123600
ISN 0034              Q(5+IVARY)=V(151)                                             00123700
ISN 0035              Q(8+IVARY)=-V(329)*1000.                                      00123800
ISN 0036              Q(37+IVARY)=V(113)                                            00123900
                C COMPUTE DISTURBANCE TORQUES
ISN 0037              Q(40)=-C(117)*V(27)+C(118)*V(28)+V(186)+C(119)*V(21)*V(22)    00123400
ISN 0038              Q(40+IVARY)=V(185)-C(121)*Z(23)+C(120)*(32.2-V(125))          00124000
                C SINCE ELEVATION AND AZIMUTH DRIVE SYSTEMS ARE VERY SIMILAR, THE SAME MODEL IS
                C USED WITH CHANGES IN PARAMATERS AND VARIABLE NAMES. AZIMUTH DRIVE TORQUES
                C ARE COMPUTED IN THE FIRST PASS(M=1) AND ELEVATION DRIVE TORQUES ARE COMPUTED
                C IN THE SECOND PASS(M=2).
ISN 0039              DO 75 M=1,2                                                   00124900
ISN 0040              IF (M.EQ.2)  GO TO 69                                         00125000
ISN 0042              I=0                                                           00125100
ISN 0043              K=-29                                                         00125200
ISN 0044              L=0                                                           00125300
```

modeling the azimuth stabilization system. DT is the integration time increment. TEST is a variable used to check the divisor before division is attempted. If the divisor is too small, the division is not performed and an alternate operation is performed.

Statements 13-25 perform a transformation from hull to turret coordinate systems on the linear and angular acceleratrons of the hull c.g. and the angular velocity of the hull. The linear acceleratrons at the gun trunnion are calculated. These statements were taken without change from the original HITPRO DRIVE subroutine (G.E. all-electric model).

Statement 26 calls subroutine RECOIL. In single shot versions of HITPRO, subroutine RECOIL is a dummy routine. Recoil forces and torques for these systems do not affect firing accuracy since the motions they induce die out before the next firing procedure is initiated. In automatic cannon versions (HITPRO II) these firing forces and torques are important and they are calculated in RECOIL. If the guidance of missile/projectiles is modeled in HITPRO, it will be necessary to include the excitation from weapon firing.

Statements 27-36 define DRIVE inputs obtained from other subroutines.

Q(1) is the hull yaw rate,

Q(2) is the turret azimuth (yaw) rate,

Q(5) is the turret azimuth rate commanded by the gunner,

Q(8) is the fire control azimuth deflection angle,

Q(37) is the turret rate relative to the hull,

Q(44) is the turret pitch rate,

Q(45) is the gun elevation (pitch) rate,

Q(48) is the gun elevation rate commanded by the gunner,

Q(51) is the fire control elevation angle,

Q(80) is the gun elevation pitch rate relative to the turret,

Statements 37-38 compute disturbance torques in azimuth and elevation. C(117) * V(27), C(118) * V(28) and C(120) * (32.2 - V(125)) are torques resulting from linear accelerations acting on mass unbalances. V(185) and V(186) are recoil torques. C(121) * Z(23) is a torque exerted by the equilibrator. C(119) * V(21) * V(22) is a gyroscopic torque.

Statement 39 Since the functional block diagram of the azimuth and elevation systems are very similar, the same model is used for both systems with

```
ISN 0045          KK=0                                                          00125400
ISN 0046          GO TO 70                                                      00125500
ISN 0047       69 I=IVARY                                                       00125600
ISN 0048          KK=5                                                          00125700
ISN 0049          K=5                                                           00125800
ISN 0050          L=58                                                          00125900
ISN 0051       70 CONTINUE                                                      00126000
            C AZIMUTH HULL GYRO                                                 00126100
            C THE FOLLOWING CHANGE IN INTEGRATOR INDEXING KEEPS THE INPUT TO HITPRO 00126300
            C CHANGED FROM PREVIOUS HITPRO DECKS                                00126400
                                                                                00126500
ISN 0052  1.5     IF(M.EQ.1) K=I                                                00126600
ISN 0054          Y(50+K)=C(2+L)*Q(1+I)-C(3+L)*2.*C(1+L)*Z(50+K)-C(2+L)*Z(51+K) 00126700
ISN 0055          Y(51+K)=Z(50+K)                                               00126800
            C INITIAL CONDITIONS, Z(50)=Z(51)=0.                                00126900
            C AZIMUTH GUN GYRO                                                  00127100
ISN 0056          Y(52+K)=C(5+L)*Q(2+I)-2.0*C(6+L)*C(4+L)*Z(52+K)-C(5+L)*Z(53+K) 00127200
ISN 0057          Y(53+K)=Z(52+K)                                               00127300
            C INITIAL CONDITIONS Z(52)=Z(53)=0.                                 00129500
            C SUMMER 1 AND HULL AMPLIFIER                                       00129600
ISN 0058          Q(6+1)=(Q(5+I)-Z(51+K))*C(14+L)                               00129700
            C SUMMER 2                                                          00129800
ISN 0059          Q(7+I)=Q(5+I)-Z(53+K)                                         00129900
ISN 0060 -29.5    IF (M.EQ.1) K=-29                                             00130000
            C AZIMUTH POSITION PATH                                             00130100
            C INTEGRATOR                                                        00130300
ISN 0062          Y(54+K)=C(15+L)*Q(7+I)                                        00130400
            C INITIAL CONDITION Z(54)=0.                                        00130500
            C RETICLE AZIMUTH INPUT TO SUMMER 3                                 00130700
ISN 0063          Y(55+K)      =(C(16+L)*Q(8+I)-Z(55+K))/C(17+L)                00130800
            C INITIAL CONDITION Z(55)=0.                                        00130900
            C RETICLE AZIMUTH INPUT TO SUMMER 4                                 00131000
ISN 0064          Q(13+I)=(C(18+L)*Q(8+I)-Z(56+K))/C(19+L)                      00131100
ISN 0065          Y(56+K)=Q(13+I)                                               00131200
            C INITIAL CONDITION Z(56)=0.                                        00131300
            C SUMMER 3  AND AMPLIFIER SATURATION
ISN 0066          Q(9+I)=Z(54+K)-Z(55+K)                                        00131700
ISN 0067          Q(10+1)=DABS(Q(9+1))                                          00132000
ISN 0068          IF(Q(10+I)-C(58+L)) 1,1,2                                     00132100
ISN 0069        2 Q(9+I)=(Q(9+I)/Q(10+I))*C(58+L)                               00132200
ISN 0070        1 CONTINUE
            C AZIMUTH LAG NETWORK (FICTIOUS)                                    00132500
ISN 0071          IF(C(20+L).EQ.0.)  GO TO 47                                   00132600
ISN 0073          Y(65+K)=(Q(9+I)-Z(65+K))/C(20+L)                              00132700
ISN 0074          Q(10+I)=Z(65+K)                                               00132800
            C INITIAL CONDITION Z(65)=0.                                        00132900
ISN 0075          GO TO 48                                                      00133000
ISN 0076       47 Q(10+I)=Q(9+I)                                                00133100
ISN 0077       48 CONTINUE                                                      00133200
            C AZIMUTH NOTCH FILTER                                              00133300
ISN 0078          Q(11+1)=(C(25+L)/C(22+L))*Q(7+I)+Z(58+K)                      00133400
ISN 0079          Y(58+K)=2.*C(23+L)*C(21+L)*(C(25+L)/C(22+L))*Q(7+I)-2.*C(24+L) 00133500
                 1*C(26+L)*Q(11+I)+Z(57+K)                                      00133600
ISN 0080          Y(57+K)=C(25+L)*(Q(7+I)-Q(11+I))                              00133700
            C INITIAL CONDITIONS Z(57)=Z(58)=0.                                 00133800
            C VELOCITY PATH AMPLIFIER                                           00133900
ISN 0081          Q(12+I)=C(27+L)*Q(11+I)
```

different parameter values. Statement 39 defines a Do Loop in which the azimuth variables are updated on the first pass (M=1) and the elevation variables are updated on the second pass (M=2).

Statements 40-51 set variable and parameter indices appropriate to the azimuth or elevation control system.

Statements 52-60 switch integration indices so that all integrators used in the original HITPRO program are utilized.

Statements 54-55 model the hull gyro. All gyros in this system are modeled as second order systems with transfer function:

$$1) \qquad \frac{0(s)}{I(s)} = \frac{\omega_g^2}{s^2 + 2\rho_g \omega_g s + \omega_g^2}$$

The relationship between the transfer function and the computer statements is well known and is explained in HITPRO, Volume II (User's Manual) AD891400L RE-TR-71-63.

Statements 56-57 model the gun gyro. These statements are equivalent to statements 54 and 55.

Statements 58-59 model summing amplifiers.

Statement 62 defines the input to the position path integrator. The output of this integrator represents the sensed pointing error of the system.

Statements 63-65 represent the filtering of the fire control computer commands before application to the gun controller. These commands are applied at two points in the servo loop, the position path and the velocity path. Statement 63 models the filter at the position path:

$$2) \qquad \frac{0(s)}{I(s)} = \frac{K_{f_1}}{1+\tau_1 s}$$

Statements 64-65 model the filter for the velocity path input. Since the fire control computer outputs position commands, it is differentiated before application to the velocity path. The transfer function of this differentiator network is:

$$3) \qquad \frac{0(s)}{I(s)} = \frac{K_{f_2} s}{1+\tau_2 s}$$

Statements 66-70 model the position path summing amplifier with amplifier saturation.

Statements 71-77 model a lag network. This network is included physically only in the elevation servo system. It is included in the azimuth model but is bypassed by setting the time constant to zero. The transfer function of this filter is:

$$4) \qquad \frac{O(s)}{I(s)} = \frac{1}{1+\tau s}$$

Statement 71 was added to bypass this filter when T is zero, because T appears in the denominator of statement 69. Even though this is mathematically correct, it would result in divide checks during execution of the program.

Statements 78-80 model a filter in the azimuth velocity path. The purpose of this filter is to limit the system bandwidth and prevent excitation of the lower system resonances. It is required in azimuth but is bypassed in elevation. The filter transfer function is:

$$5) \qquad \frac{O(s)}{I(s)} = \frac{\omega_2^2}{\omega_1^2} \frac{s^2+2\rho_1\omega_1 s+\omega_1^2}{s^2+2\rho_2\omega_2 s+\omega_2^2}$$

Statement 81 models a perfect amplifier.

Statements 82-83 model the acceleration path of the system. The acceleration path model is included in a separate subroutine because the integration time increment required to obtain a convergent solution is very small. To use this integration time increment for all integrators would result in long and expensive computer runs. Subroutine DERIDE employs a second order Runge-Kutta integration procedure and models the differentiator network described by the the transfer function:

$$6) \qquad \frac{O(s)}{I(s)} = \frac{\omega_D^2 K_a s}{s^2+2\rho_D\omega_D s+\omega_D^2}$$

Statement 84 models a summing amplifier. The output of this summing amplifier corresponds to the output of the system low level electronics.

Statement 85 models the servo value position response. The servo valve is better represented by the closed loop shown in Figure 2, however, in debugging the model it was found that the response of the valve is sufficiently fast that it can be simplified with little loss in model accuracy. If it is desired to model the servo valve in detail, the comments symbol on the FORTRAN Statements between statements 85 and 86 can be removed and Statement 85 commented.

```
                C ACCELERATION PATH AZIMUTH                                                  00134000
ISN 0082              Q(38+I)=Q(11+I)                                                        00134100
ISN 0083              CALL DERIDE
                C  SUMMER 5                                                                  00135100
ISN 0084              Q(14+I)=Q(6+I)+Z(60+K)+Q(10+I)-Q(13+I)+Q(12+I)
                C THIRD STAGE CLOSED LOOP AZIMUTH                                            00135300
ISN 0085              Q(17+I)=Q(14+I)/C(32+L)
                C THE HYDRAULIC SERVO VALVE  HAS   A FAST RESPONSE AND IS NOT MODELED IN DETAIL.
                C IF IT IS DESIRED  TO MODEL THE SERVOVALVE, MERELY REMOVE THE COMMENT LABELS ON
                C ALL FORTRAN STATEMENTS BETWEEN HERE AND STATEMENT 53 AND COMMENT
                C THE ABOVE FORTRAN STATEMENT << Q(17+1)=Q(14+1)/C(32+L) >>
                C SUMMER 6                                                                   00135400
                C      Q(15+1)= Q(14+I)-C(32+L)*Q(17+1)                                      00135500
                C AMPLIFIER SATURATION (AZIMUTH)                                             00135800
                C      Q(16+I)=DABS(Q(15+1))                                                 00135900
                C      IF (Q(16+I)-C(33+L)) 51,51,52                                         00136000
                C  52 Q(15+I)=(Q(15+I)/Q(16+I))*C(33+L)                                      00136100
                C  51 CONTINUE                                                               00136200
                C  THIRD STAGE SERVO VALVE(AZIMUTH)                                          00136300
                C      Y(61+K)=C(36+L)*C(34+L)*Q(15+I)-2.*C(37+L)* C(35+L)*Z(61+K)-          00136500
                C     IC(36+L)*Z(62+K)                                                       00136600
                C      Y(62+K)= Z(61+K)                                                      00136700
                C INITIAL CONDITIONS Z(61)=Z(62)=0.                                          00136800
                C SECOND STAGE INTEGRATOR                                                    00136900
                C      Q(39+T)=Z(62+K)                                                       00137000
                C      Y(63+K)=Q(39+I)/C(38+L)                                               00137200
                C INITIAL CONDITION Z(63)=0.                                                 00137300
                C THIRD STAGE SPOOL LIMIT(AZIMUTH)                                           00137400
                C      Q(17+I)=Z(63+K)                                                       00137500
                C      Q(18+I)=DABS(Z(63+K))                                                 00137800
                C      IF(Q(18+1)-C(39+L))  53,53,54                                         00137900
                C  54 Q(17+I)=(Z(63+K)/Q(18+I))*C(39+L)                                      00138000
ISN 0086           53 CONTINUE                                                               00138100
                C THIRD STAGE OVERLAP                                                        00138200
ISN 0087              Q(20+T)=DABS(Q(17+I))                                                  00138300
ISN 0088              IF(Q(20+1)-C(40+L)) 55,55,56                                           00138400
ISN 0089           55 Q(19+I)=0.                                                             00138500
ISN 0090              GO TO 57                                                               00138600
ISN 0091           56 Q(19+1)=(Q(17+I)/Q(20+I))*(Q(20+1)-C(40+L))                            00138700
ISN 0092           57 CONTINUE                                                               00139000
ISN 0093              Q(25+I)=2.*(C(49+L)/C(50+L))*Z(64+K)                                   00142400
ISN 0094              V(113)=Z(21)-V(21)                                                     00147600
ISN 0095              V(114)=Z(22)-V(162)                                                    00147700
                C HYDRAULIC MOTOR (AZIMUTH)                                                  00139100
                C FLOW EQUATION                                                              00139200
ISN 0096              Q(31+I)=DABS(Q(19+I))                                                  00139300
ISN 0097              IF(Q(31+I)-TEST) 900,901,901                                           00139400
ISN 0098          900 Q(29+I)=C(41+L)                                                        00139500
ISN 0099              GO TO 902                                                              00139600
ISN 0100          901 Q(29+I)=C(41+L)-Q(25+I)*(Q(19+I)/Q(31+I))                              00139700
ISN 0101          902 IF(Q(29+I)) 58,58,59                                                   00139800
ISN 0102           58 Q(19+I)=0.                                                             00139900
ISN 0103              GO TO 60                                                               00140000
ISN 0104           59 Q(30+1)=Q(29+I)/(1.+Q(19+I)*Q(19+I)*C(42+L)*C(42+L)*C(43+L))           00140100
ISN 0105              Q(19+I)=Q(19+I)*C(42+L)*DSQRT(Q(30+I))                                 00140200
ISN 0106           60 CONTINUE                                                               00140300
```

```
                  C CROSS OVER RELIEF VALVE
ISN 0107                Q(32+I)=DABS(Q(25+I))
ISN 0108                IF (Q(32+I)-C(45+L)) 6I,6I,62
ISN 0109             61 Q(21+I)=0.
ISN 0110                GO TO 63
ISN 0111             62 Q(33+I )=(Q(32+I))
ISN 0112                Q(21+I)=  (Q(25+I)/Q(32+I))*C(44+L)*DSQRT(Q(33+I))
ISN 0113             63 CONTINUE
                  C ORIFICE EQUATION
ISN 0114                IF(Q(32+I)-TEST) 903,904,904
ISN 0115            903 Q(22+I)=0.
ISN 0116                GO TO 905
ISN 0117            904 Q(22+I)=(Q(25+I)/Q(32+I))*DSQRT(Q(32+I))*C(46+L)
                  C OIL LEAKAGE
ISN 0118            905 Q(23+I)=C(47+L)*Q(25+I )
                  C MOTOR DISPLACEMENT
ISN 0119                Q(24+I)=C(48+L)*Q(37+I)
                  C OIL COMPLIANCE
ISN 0120                Y(64+K)=Q(19+I)-Q(21+I)-Q(22+I)-Q(23+I)-Q(24+I)
                  C MOTOR TORQUE
ISN 0121                Q(26+I)=Q(25+I)*C(48+L)/12.
ISN 0122                V(109-M)=Q(26+I)
                  C FRICTION TERMS
ISN 0123                Q(34+I)=C(51+L)*C(51+L)*C(52+L)*Q(37+I)
ISN 0124                Q(26+I)=Q(26+I)+Q(40+I)-Q(34+I)
ISN 0125                Q(35+I)=DABS(Q(37+I))
ISN 0126                IF (Q(35+I)-TEST)  801,801,911
ISN 0127            911 Q(36+I)=C(51+L)*C(54+L)*Q(37+I)/Q(35+I)
ISN 0128                Q(28+I)=Q(26+I)-Q(36+I)
ISN 0129                GO TO 75
ISN 0130            801 IF(DABS(Q(26+I)).LE.C(51+L)*C(54+L))  GO TO 65
ISN 0132                Q(36+I)=C(51+L)*C(54+L)*Q(26+I)/(DABS(Q(26+I)))
ISN 0133                Q(28+I)=Q(26+I)-Q(36+I)
ISN 0134                GO TO 75
ISN 0135             65 CONTINUE
ISN 0136                Q(36+I)=Q(26+I)
ISN 0137                Q(28+I)=Q(26+I)-Q(36+I)
ISN 0138             75 CONTINUE
                  C EVALUATE TORQUES TO RETURN TO MAIN PROGRAM
                  C RECOIL TORQUES AND FORCES ARE NOT COMPUTED
ISN 0139                V(105)=V(184)*V(149)
ISN 0140                V(108)=V(108)*(-1.0)
ISN 0141                V(106)=(-V(184)*CT(29)*V(148)-V(107))*V(147)
ISN 0142                V(107)=(-V(184)*CT(29)*V(148)-V(107))*V(146)
ISN 0143                Y(22)=Q(28)*.00005
                  C
                  C  CHANGE INERTIA OF GUN IN ELEVATION  JUNE 5, 1973
                  C
                  C   **********
                  C     Y(21)=Q(28+IVARY)*.00125
ISN 0144                Y(21)=Q(28+IVARY)/586.
                  C   **********
                  C
ISN 0145                Y(23)=Z(21)-V(21)
ISN 0146                Y(24)=Z(22)-V(162)
ISN 0147                V(333)=Z(22)
```

sufficiently fast that it can be simplified with little loss in model accuracy. If it is desired to model the servo valve in detail, the comments symbol on the FORTRAN Statements between statements 85 and 86 can be removed and Statement 85 commented.

Statements 87-92 calculate the effective area of the servo-value orifice. Since the servo-value has overlap, there is a deadband or region around the null position where piston motion does not result in fluid flow. This deadband is included in the model.

Statements 93-106 when the spool valve opens, the hydraulic fluid can flow. The amount of flow is proportional to the square root of the pressure differential across the valve where the proportionality constant is a function of the servo valve displacement.

$$7) \qquad Q = X_s K_1 \sqrt{P/\left(1+X_s^{\,2} K_1^{\,2} K_2\right)} \qquad P>0$$
$$Q = 0 \text{ if } P \le 0$$

This a more or less standard orifice equation, where

$$8) \qquad P = P_s - P_L \operatorname{sgn}(X_s)$$

and P_s is the supply pressure, X_s is the spool valve position, and K_1 and K_2 are valve parameters. P_L is the pressure in the actuator. There is a check valve that prevents oil from flowing back into the source in the event the P_L becomes larger than source pressure P_s. The denominator term under the square root is nearly 1, for most cases of interest. The oil that flows through the spool valve follows one of 5 routes: it is compressed; it leaks by the motor/actuator; it flows through the motor actuator; it flows through the bypass pipe; it flows through the pressure relief valve.

Statements 107-113 model a pressure relief valve. The hydraulic pressure may become very large when the actuator dissipates the load kinetic energy. The actuator then acts as a pump and the hydraulic pressure rises until the relief valve opens.

Statements 114-117 model flow rate through the motor bypass orifice in the azimuth system. There is no bypass system in elevation.

Statement 118 calculates the flow rate due to leakage in the azimuth motor. Leakage in the elevation system is neglected.

Statement 119 calculates the flow rate through the actuator due to load motion.

Statements 120 and 93 calculate the pressure across the actuator which results from compression of hydraulic fluid.

Statements 121-122 calculate the actuator torque which is directly proportional to the pressure across the actuator.

Statements 123-138 determine the friction torque.

Statements 139-142 evaluate reaction forces and torques which are used in subroutine MOTION in predicting hull motion.

Statements 143-146 calculate turret/gun accelerations and relative velocities.

SUBROUTINE DERIDE

This subroutine models the acceleration path differentiator network whose transfer function is given by equation 6. This subroutine employs an integration procedure distinct from that of the main program but identical except for the reduced step size.

Statements 13-14 of this subroutine model the differentiator transfer function.

All other statements are related to the integration procedure.

```
                C                                                            00149000
                C   SET PRINT-OUT CHANNELS                                   00149100
                C                                                            00149200
ISN 0148              V(397)=V(21)                                           00152100
ISN 0149              V(398)=V(23)                                           00152200
ISN 0150              V(399)=V(24)                                           00152300
ISN 0151              RETURN                                                 00155500
ISN 0152              END                                                    00155600
```

```
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,XREF
                 C
ISN 0002               SUBROUTINE DERIDE                                                     00082500
ISN 0003               IMPLICIT REAL*8(A-H,O-Z)                                              00082600
ISN 0004               COMMON T,D,TS,Y,Z,V,C,CG,CS,CT,CW,CB,CP,CH,ZS,Q,NT,NW,KB,KO,N1,N2,00082700
                      $ N3                                                                   00082800
ISN 0005               DIMENSION Y(90),Z(90),V(400),C(150),CG(96),CS(40),CT(40),CW(56),   00082900
                      1CB(78),KB(78),KO(32),CP(800),CH(50),ZS(90),TITLE(20),Q(99)           00083000
ISN 0006               COMMON/TEMP/DT,I,K,L                                                  00083100
ISN 0007               IOP=25                                                                00083200
ISN 0008               POI=FLOAT(IOP) *2.                                                    00083300
ISN 0009               DET=DT/POI                                                            00083400
ISN 0010               DO1011 IV=1,IOP                                                       00083500
ISN 0011               IZ=-1                                                                 00083600
ISN 0012          1012 CONTINUE                                                              00083700
ISN 0013               Y(60+K)=C(30+L)*C(28+L)*Q(38+I)-2.*C(31+L)*C(29+L)*Z(60+K)+Z(59+K)00083800
ISN 0014               Y(59+K)=-C(30+L)*Z(60+K)                                              00083900
ISN 0015               IF(IZ) 1013,1013,1014                                                 00084000
ISN 0016          1013 ZS(59+K)=Z(59+K)                                                      00084100
ISN 0017               ZS(60+K)=Z(60+K)                                                      00084200
ISN 0018               Z(59+K)=ZS(59+K)+Y(59+K)*DET/2.                                       00084300
ISN 0019               Z(60+K)=ZS(60+K)+Y(60+K)*DET/2.                                       00084400
ISN 0020               IZ=1                                                                  00084500
ISN 0021               GO TO 1012                                                            00084600
ISN 0022          1014 Z(59+K)=ZS(59+K)+Y(59+K)*DET                                          00084700
ISN 0023               Z(60+K)=ZS(60+K)+Y(60+K)*DET                                          00084800
ISN 0024               IZ=-1                                                                 00084900
ISN 0025          1011 CONTINUE                                                              00085000
ISN 0026               RETURN                                                                00085100
ISN 0027               END                                                                   00085200
```

A.3.4 Key Internal Variables

PHYSICAL QUANTITY	VARIABLE NAME AZ	EL	UNITS
Hull/Turret Space Rate	$Q_{(1)}$	$Q_{(44)}$	rad/sec
Gun Space Rate	$Q_{(2)}$	$Q_{(45)}$	rad/sec
Gunner Rate Command	$Q_{(5)}$	$Q_{(48)}$	rad/sec
Fire Control Offsets	$Q_{(8)}$	$Q_{(51)}$	mr
Turret/Gun Relative Rate	$Q_{(37)}$	$Q_{(80)}$	rad/sec
Torques on Gun due to hull motion	$Q_{(40)}$	$Q_{(83)}$	ft-lb
Hull/Turret Gyro Output	$Z_{(52)}$	$Z_{(56)}$	rad/sec
Gun Gyro Output	$Z_{(54)}$	$Z_{(58)}$	rad/sec
Position Path Integrator	$Z_{(25)}$	$Z_{(59)}$	ma
Fire Control Input to Position Path	$Z_{(26)}$	$Z_{(60)}$	ma
Fire Control Feed Forward Input	$Z_{(27)}$	$Z_{(61)}$	ma
Velocity Path Output	$Q_{(12)}$	$Q_{(55)}$	ma
Position Path Output	$Q_{(10)}$	$Q_{(53)}$	ma
Acceleration Path Output	$Z_{(31)}$	$Z_{(65)}$	ma
Low Level Electronics Output	$Q_{(14)}$	$Q_{(57)}$	ma
Servo Valve Position	$Q_{(17)}$	$Q_{(60)}$	inches
Hydraulic Flow	$Q_{(19)}$	$Q_{(62)}$	inches^3
Actuator Differential Pressure	$Q_{(25)}$	$Q_{(68)}$	psi
Actuator Torque	$Q_{(26)}$	$Q_{(69)}$	ft-lb
Total Drive System Torque	$Q_{(28)}$	$Q_{(71)}$	ft-lb

A.3.5 Input and Output Variables

PHYSICAL QUANTITY	VARIABLE NAME AZ	VARIABLE NAME EL	UNITS
Reticle Servo Command	$V_{(330)}$	$V_{(329)}$	radians
Gun Relative Angular Velocity	$V_{(114)}$	$V_{(113)}$	rad/sec
Gunner Rate Command	$V_{(152)}$	$V_{(151)}$	rad/sec
Hull Fore-Aft Acc. X	$V_{(155)}$		ft/sec^2
Hull Side-Side Acc. Z	$V_{(156)}$		ft/sec^2
Hull Vertical Acc. Y	$V_{(157)}$		ft/sec^2
Hull Roll Angular Acc. X	$V_{(158)}$		rad/sec^2
Hull Yaw Angular Acc. Y	$V_{(160)}$		rad/sec^2
Hull Fore-Aft Velocity X	$V_{(161)}$		ft/sec
Hull Side-Side Velocity Z	$V_{(162)}$		ft/sec
Hull Vertical Velocity Y	$V_{(163)}$		ft/sec
Gun Recoil Force	$V_{(184)}$		lbs
Gun Recoil Torque El.	$V_{(185)}$		ft-lbs
Gun Recoil Torque Az.	$V_{(186)}$		ft-lbs
Cosine of Gun Azimuth Angle	$V_{(146)}$		-
Sine of Gun Azimuth Angle	$V_{(147)}$		-
Cosine of Gun Elevation Angle	$V_{(148)}$		-
Sine of Gun Elevation Angle	$V_{(149)}$		-
Turret Roll Acceleration	$V_{(332)}$		rad/sec^2
Turret Pitch Acceleration	$V_{(223)}$		rad/sec^2
Turret "Vertical" Acceleration	$V_{(125)}$		ft/sec^2
Vertical Force due to Firing	$V_{(105)}$		lbs
Roll Torque due to Firing	$V_{(106)}$		ft-lbs
Pitch Torque due to Firing	$V_{(107)}$		ft-lbs
Yaw Torque due to Firing	$V_{(108)}$		ft-lbs

A.3.6 HITPRO Integrators Updated In Drive Routine

VARIABLE NAME	AZ	EL
Z(50+K)	Z(51)	Z(55)
Z(51+K)	Z(52)	Z(56)
Z(52+K)	Z(53)	Z(57)
Z(53+K)	Z(54)	Z(58)
Z(54+K)	Z(25)	Z(59)
Z(55+K)	Z(26)	Z(60)
Z(56+K)	Z(27)	Z(61)
Z(57+K)	Z(28)	Z(62)
Z(58+K)	Z(29)	Z(63)
Z(64+K)	Z(35)	Z(69)
Z(65+K)	Z(36)	Z(70)
Z(21)	-	Z(21)
Z(22)	Z(22)	-
Z(23)	-	Z(23)
Z(24)	Z(24)	-

A.3.7 HITPRO Integrators Updated In Subroutine Deride

VARIABLE NAME	AZ	EL
Z(59+K)	Z(30)	Z(64)
Z(60+K)	Z(31)	Z(65)

A.3.8 Table Of Control System Constants

DESCRIPTION OF CONSTANT	FORTRAN SYMBOL AZ	FORTRAN SYMBOL EL	VALUE AZ	VALUE EL	UNITS
Gyro Natural Frequency	C(1) C(4)	C(59) C(62)	184	184	rad/sec
(above squared)	C(2) C(5)	C(60) C(63)	33860	33860	$(rad/sec)^2$
Gyro Damping Factor	C(3) C(6)	C(61) C(64)	.07	.07	-
(not used)	C(7) -C(13)	C(65) -C(71)	-	-	-
Hull/Turret Gyro Gain	C(14)	C(72)	12.92	15.7	ma/rad/sec
Position Path Gain	C(15)	C(73)	451	450	ma/rad
F.C. Computer Pos. Filter Gain	C(16)	C(74)	.626	.7615	ma/mil
F.C. Computer Pos. Filter Time Const.	C(17)	C(75)	.011	.011	sec
F.C. Computer Vel. Filter Gain	C(18)	C(76)	.0294	.0432	ma/mil
F.C. Computer Vel. Filter Time Const.	C(19)	C(77)	.00475	.003	sec
Lag Network Time Constant	C(20)	C(78)	0.0	.04	sec
Notch Filter Numerator Natural Frequency	C(21)	C(79)	250.	1.0	rad/sec
(above quantity squared)	C(22)	C(80)	62500	1.0	$(rad/sec)^2$
Notch Filter Numerator Damping Ratio	C(23)	C(81)	.17	1.0	-

Table Of Control System Constants (cont'd)

DESCRIPTION OF CONSTANT	FORTRAN AZ	SYMBOL EL	VALUE AZ	VALUE EL	UNITS
Notch Filter Denominator Natural Frequency	C(24)	C(82)	93	1.0	rad/sec
(above quantity squared)	C(25)	C(83)	8649	1.0	$(rad/sec)^2$
Notch Filter Denominator Damping Factor	C(26)	C(84)	.59	1.0	-
Velocity Path Gain	C(27)	C(85)	37.8	2.66	-
Acc Path Gain	C(28)	C(86)	.365	.033	$ma/rad/sec^2$
Diff. Denominator Natural Frequency	C(29)	C(87)	407	407	rad/sec
(above quantity squared)	C(30)	C(88)	165649	165649	$(rad/sec)^2$
Diff. Denominator Damping Factor	C(31)	C(89)	.11	.11	-
Servo Valve Feedback Gain	C(32)	C(90)	62.4	83.9	ma/in
(not used)	C(33) -C(39)	C(91) -C(97)	-	-	-
Spool Overlap	C(40)	C(98)	.0024	.0024	in
Accumulator Pressure	C(41)	C(99)	2000	2000	psi
Third Stage Hydraulic Coefficients	C(42) C(43)	C(100) C(101)	6.2 .478	6.04 .382	- -

Table Of Control System Constants (cont'd)

DESCRIPTION OF CONSTANT	FORTRAN	SYMBOL	VALUE		UNITS
	AZ	EL	AZ	EL	
Pressure Relief Valve Hydraulic Gain	C(44)	C(102)	.00122	0	-
Relief Pressure	C(45)	C(103)	2150	2800	psi
Orifice Hydraulic Gain	C(46)	C(104)	.0336	0	-
Leakage Constant	C(47)	C(105)	1.7×10^{-4}	0	in^3/psi
Hydraulic Displacement	C(48)	C(106)	51.584	48.84	in^3/rad
Oil Compliance Coefficient	C(49)	C(107)	12450	5050	$lb/in^2/in^3$
Oil Compliance Coefficient	C(50)	C(108)	1.0	1.0	-
Coulomb Friction	C(51)	C(109)	640	420	ft-lb
Friction Coefficient	C(52)	C(110)	.00109	1.0	-
(not used)	C(53)	C(111)	-	-	-
Friction Coefficient	C(54)	C(112)	1.375	0.0	-
(not used)	C(55) -C(57)	C(113) -C(115)	-	-	-
Integration Current Limit	C(58)	C(116)	10.3	10.3	ma

Table Of Control System Constants (cont'd)

DESCRIPTION OF CONSTANT	FORTRAN AZ	SYMBOL EL	VALUE AZ	VALUE EL	UNITS
Turret Mass Unbalance*	C(117)	-	127	-	slugs
Turret Mass Unbalance*	C(118)	-	-390	-	slugs
Turret Inertia*	C(119)	-	9120	-	$slugs/ft^2$
Gun Mass Unbalance*	-	C(120)	-	68.4	slugs
Equilibrator Spring Constant*	-	C(121)	-	993	ft-lb/rad

*Taken from GE HITPRO model

APPENDIX B

TEST PLANS

Two of the three plans used to conduct the tests described in Sections 2.2, 2.3, and 2.4 are included. The test plan for the data collection described in Section 2.3 is very similar to plan B.1; therefore, to avoid redundancy, it is not included.

B.1 EDT Plan for M60A1E2 Tank with All Electric Gun Drives

TPR #AMSWE-REV-106
USATECOM Proj No 1-VC-08F-060-008

ENGINEER DESIGN TEST PLAN
OF GENERAL ELECTRIC STABILIZATION SYSTEM
FOR TANK, COMBAT, FULL-TRACKED
152MM GUN, M60A1E2

REVISED OCTOBER 1970

ANNOTATED IN NOVEMBER-DECEMBER TEST

TANK SYSTEMS LABORATORY
RESEARCH AND ENGINEERING DIRECTORATE
UNITED STATES ARMY WEAPONS COMMAND
ROCK ISLAND, ILLINOIS

TABLE OF CONTENTS

SECTION 1 - INTRODUCTION

1.1 Project Identification

1.1.1 Authority

a. Work Directive AMSWE-REP/CPFM to STEAP-CO-R, AMCMS Code 552C.12.24100.10, PRON Number M1-0-50063-(03)-M1-K2, dated 0253, in the amount of $11,000.

b. Work Directive AMSWE-REP/CPFM to STEAP-CO-R, AMCMS Code 553A.12.38000.05, PRON Number M1-0-50293-(01)-M1-K2, dated 0253, in the amount of $71,000.

1.1.2 Test Site: Aberdeen Proving Ground.

1.1.3 Test Category II

1.2 Description of Material

The G.E. Tank Stabilization System is an optimum-ratio electrical stabilization and gun control system, designed to stabilize both the main and secondary armament of the M60A1E2 tank. This stabilization system has been installed in two M60A1E2 tanks, replacing the original electro-hydraulic system.

1.3 Test Objectives

The test objectives are:

1.3.1 To evaluate the stabilization of the main weapon while firing on the move.

1.3.2 To collect test data suitable for validating the HITPRO (hit probability) computer mathematical model.

1.3.3 To ascertain gunner and loader human factors.

1.4 Purpose of Test Plan

The purpose of this test plan is to provide a viable guide to achieving the test objectives. Changes should be coordinated with either Stanley M. Birley, Autovon 433-1700, extension 6855/6817, or Harold J. Liberman, TDY extension at APG 2573/2969.

SECTION 2 - DETAILS OF TEST

2.1 Firing Tests

Only XM411E4 rounds from the same ammunition lot will be used. Stationary and moving targets will be used, with the tank traveling over the bump course, the zig-zag course, the gravel course, and cross country. The moving targets will travel at approximately right angles to the tank course, and stationary targets will be approximately in line with the tank course. Starting range will be 1500 meters. It is preferable that all test runs use two gunners and that test runs on the test courses be staggered. The test runs, listed below, are subject to change based on facility and equipment limitations.

	Tank Speed	Target Speed	Mimimum Rounds
2.1.1 Test Fire	0	0	10
2.1.2 Bump Course	7	0	18-21
	12	0	18-21
	7	15	18-21
	12	15	18-21
	7	30	18-21
	12	30	18-21
2.1.3 Zig-Zag Course	7	0	18-21
Because of time required for lead angle insertion, it is anticipated that only a single tank speed of 4-7 MPH will be practical	15	0	18-21
	7	15	18-21
	15	15	18-21
	7	30	18-21
	15	30	18-21
2.1.4 Gravel Course	7	0	18-21
	15	0	18-21

		Tank Speed	Target Speed	Minimum Rounds
		7	15	18-21
		15	15	18-21
		7	30	18-21
		15	30	18-21
2.1.5	Cross Country	7	0	18-21
	Stationary targets will not be in line with the Tank course	15	0	18-21
		7	15	18-21
		15	15	18-21
		7	30	18-21
		15	30	18-21
				490 approx.

2.2 Test Data

2.2.1 Data Items

a. Gun mounted gyro outputs

b. Elevation and traverse tachometer outputs

c. Roll Rate (from cupola elevation gun gyro at 90°)

d. Gunner's hand station inputs

e. Reticle position inputs

f. Relative turret to hull position

g. Relative gun to turret position

h. Turret mounted linear accelerometers to measure vertical and lateral accelerations

i. Target lead from ballistic computer

j. Gunner's helmet and brow pad accelerometers

k. Computer lead and cancel events

l. Removal of round from stowage rack

m. Breech open and close events

n. Ready fire switch events

o. Tape monitor of intercom system

p. Debriefing for recording unusual trails

q. A boresight camera located outside on the front of the gun mantlet is to be used to get film data for run.

r. Time, position, tank speed, conditions for each shot, and impact of each shot relative to target center.

s. Wind magnitude and direction.

t. A camera mounted on gun tube near trunnion is to be used to get film data for non-firing tests.

u. Split image camera (mounted on gunner's periscope) is to be used to get film data for dry runs and also for firing runs as required.

v. Camera is to be used to get film data of gunner and loader on some firing.

2.2.2 Data Collection

a. Data items 2.2.1a - 2.2.1j will be recorded on a multichannel recorder as simultaneous analog information. Data items 2.2.1r and 2.2.1s are to be recorded manually. Tank speed will also be recorded on a multichannel recorder.

b. Firing tests will not be cancelled due to failure of instrumentation. Only reasonable delays for instrumentation maintenance can be tolerated.

c. Generally film will be provided by General Electric and developed by photography service available from Aberdeen Proving Ground.

d. Generally all raw data will be collected by General Electric and subsequently delivered to AMSWE-REV-AC.

2.3 Responsibility Areas

2.3.1 Test Data Responsibilities

a. General Electric will provide, install, calibrate, and maintain all sensors and recording equipment for data items 2.2.1a - 2.2.1i.

b. Human Engineering Laboratory (HEL) will supply sensors and helmet; GE will provide recorder for data item 2.2.1j.

c. HEL will supply camera, sensors, and recording equipment for data items 2.2.1k - 2.2.1o and data item 2.2.q.

d. Material Test Directorate (MTD) will record data items 2.2.1r and 2.2.1s.

e. HEL will supply camera for data items 2.2.1t and 2.2.1v.

f. MTD will supply camera for data item 2.2.1u.

g. General Electric is responsible for overall compatibility of the instrumentation and for instrumentation operation.

2.3.2 General Electric will reduce the data into suitable form for forwarding to AMSWE-REV-AC. Secondary distribution will by by AMSWE-REV-AC.

2.3.3 General Electric personnel will provide maintenance services for the stabilization equipment for the duration of the test program. Spare parts will be furnished bv USAWECOM or obtained from limited supply on hand at MTD, or cannibalized from GE Pilot Number 2 at APG.

2.3.4 MTD will supply the required gunner(s), loader, driver, test director, and spotter for conducting the tests; also they will provide vehicle maintenance.

2.3.5 Chrysler will provide maintenance of fire control other than GE stabilization and will provide technical support, as required, to MTD.

2.4 Test Schedule

Instrumentation	-	30 days
Orientation and Training	-	3 days
Firing Tests, Main Gun	-	2 months

Firing to be initiated in mid-October 1970.

SECTION 3 - APPENDICES

APPENDIX I. AMSAA SUGGESTED MOVING FIRE E.D. TEST INSTRUCTIONS

Phase I (Non-Firing)

Purposes:

a. To determine if the split beam camera is required to determine the position of the reticle in the gunner's periscope.

b. To determine if there is substantial relative motion between the mantlet camera axis and the gun tube camera axis.

c. To demonstrate the adequacy of procedures and instrumentation for the subsequent live fire runs.

d. To determine the gunner's capability to accurately and consistently lay on the center of the turret ring on a tank target silhouette.

Procedure:

a. On a target mark the horizontal and vertical displacements from the centerline of the bore at the trunnion for the mantlet camera axis, the gun tube camera axis, and the V-block telescope axis. Aim the V-block telescope at its reference mark and the two cameras at their respective reference marks. This will establish parallel axes for these three instruments. Insert the target range in the computer (computer "on", in boresight mode; cant unit off; zero cross wind) and aim the periscope (reticle and split beam camera) at the mark for centerline of the bore using the gunner's boresight knobs. This will establish a hypothetical axis, parallel to the other three, from which parallax corrections are made for the gunner's periscope.

Notes:

(1) Target range - 500 meters

(2) Expose a few frames of film to record camera positions.

(3) Record aim point on target for V-block telescope and muzzle telescope.

(4) Remove muzzle telescope, re-aim V-block telescope, repeat

film exposure procedure and record position of V-block telescope. The V-block telescope is located in the coax machine gun position.

b. Conduct maximum target and tank speed runs on each course using procedures as described in live fire runs, except all loading operations to be simulated. (Do Procedure under IIIa beginning and end of day).

c. With target silhouette at 1500 meters, each gunner is to aim at the center of the turret ring and expose a few frames of film using the split beam camera. This procedure is to be repeated ten times for each gunner. The sight is to be moved off target by slewing the turret and elevating the gun and the brow pad loosened and readjusted between exposures. Repeat this procedure for a 500 meter range.

Phase II (Zeroing)

Purpose: To establish an accurate zero setting for use during the live firing - moving fire test.

Procedure:

a. Set up a 20x20 foot target at 1200 meters from tank gun muzzle.

b. Target to have an aiming cross/Bullseye.

c. Point vehicle at target.

d. Position vehicle on level concrete pad.

e. Computer on - cant unit off - normal mode.

f. Range setting 1200 meters.

g. Stabilizer off.

h. Fire with emergency fire switch.

i. Operate cameras (mantlet and split beam) during firing of each round.

j. Record wind velocity and direction, air temperature and barometer.

k. Fire 10 rounds with same sight picture.

l. Measure impact points.

m. Calculate center of impact.

n. Mark center of impact on target.

o. Aim gunner's periscope at target center.

p. Move reticle to C.I. using zeroing knobs.

q. Record gunner's and commander's boresight and gunner's jump knob positions.

r. Fire two confirming rounds. (Operate cameras for these rounds too.)

s. Record V-block telescope's aim point with gunner's periscope aimed at target center.

t. As soon as possible after firing the final confirming round, insert the muzzle telescope and record the muzzle position at 15-second intervals (longer periods if adequate to describe motion) until no motion is observed in a five-minute period.

u. Record the time lapse between all rounds, the time from the last round till the first reading, and the time between readings.

v. Describe general weather conditions.

Phase III (Firing Runs)

Purpose: To collect sight and gun pointing data, rate of fire information, and stabilization data while firing on the move at stationary and moving targets.

Procedure:

a. At the beginning of each run and the end of each day (frequency of this instrumentation check may be reduced on review of initial film data).

(1) Move tank to zeroing pad.

(2) Position 1/2 m grid target at 500 meters.

(3) Aim V-block telescope at center of target.

(4) Run mantlet camera,

(5) Record muzzle telescope axis position,

(6) With computer on, boresight mode - cant unit off - stabilization off, record gunner's periscope axis position.

b. The following procedure is to be followed for each of the live fire runs.

Start with a XM411 round in chamber and the turret aligned with hull. Load two additional XM411 rounds in racks to immediate right of loader and one dummy round in rack to immediate left of loader. Load all other turret racks with dummy ammunition. (This is subject to change during runs with pictures being taken in the turret.)

During moving target runs, the tank and the target should be operated such that the target enters the straight section of the moving target track at the specified speed at approximately the same time the tank reaches the 1500 meter mark on the course being transversed by the tank. (For the stationary target runs on the gravel, zig-zag, and bump courses the target is to be aligned with the longitudinal axis of the course. On the stationary target runs on the cross country course the target should be as far to the side as range safety permits.)

The start of the straight section of the moving target course should be marked so the commander can start his fire command as the target starts down the straight section. The gunner should respond to the fire command (no traversing of the turret prior to the initial command.) (The elements of the fire command are listed later).

When the gunner would normally range with the laser rangefinder the gunner will announce "Range." At this signal the commander will dial the range displayed on the next range pole. (Range poles will be marked with even 50 meter increments but placed 25 meters farther from the target than the indicated range.) It was estimated that the tank would travel 25 meters beyond pole before firing. When the commander has inserted the range, he will announce "Range in." As each round is fired the driver will eject a "Bean Bag" to mark the position of the tank at the time of firing through the escape hatch.

Following the firing of each round the commander will announce on the intercom the range (estimated to nearest 5 meters) displayed on his manual range input. Two subsequent rounds will be fired with emphasis on safety and rapid, accurate firing. The dummy round will be loaded following the firing of the three live rounds. The loading of the dummy round must not be delayed by wiping the breech cup or even looking for residue.

In the event the moving target goes beyond the end of the straight section* before firing the third round, terminate the run immediately. If the moving target goes beyond the straight section after the third round but before completion of the simulated firing of the fourth round, continue the operation as though the target were still moving at a constant rate.

During the runs a spotter in a bombproof near the target will record appropriate information to associate the firing sequence and the impact sequence of the rounds. Impact positions will be recorded (nearest 1 cm). Target (20x20 feet) will have M551 silhouette and two reference marks. Gunner will be instructed to aim at center of turret ring.

Two gunners and two loaders will be used. Target motion L-R for two runs each condition, each gunner and R-L for one run each gunner, each condition. Additional runs, as required, will be made to attain minimum rounds for each test condition.

*The moving target track should be marked with poles so that the commander can recognize when the target has gone beyond the firing limit.

ADDITIONAL INFORMATION AND INSTRUCTIONS

1. The split beam camera will operate at 32 frames per second and accommodate 100 ft. rolls of film.

2. The mantlet camera and gun tube camera will operate at 48 frames per second and accommodate 200 ft. rolls of film.

3. All rolls of film will include a few frames at the beginning which are coded to indicate the nature of the test results recorded on that particular roll. (Include camera code.)

4. Each time consecutive exposures are of the same target, they should be separated by a few unexposed frames.

5. Boresight and zero knobs are easily read with a .1 ₥ difference at the same setting.

6. A dimensioned layout of the moving target track, all target positions, the gravel, zig-zag, and bump courses, and all other firing and sighting positions will be required. Distances should be accurate to ± 5 meters.

7. All cameras are to incorporate 100 cycle timing marks during simulated and live fire runs. One-thousand cycle timing marks should indicate the pulling of the trigger.

8. Firing commands:

Commander	Gunner	Loader
Gunner		
HEAT		
Tank (Moving Tank)		
Traverse Left (Traverse Right)		
Steady		
On	Identified	
	Range	
Range-in**		
Fire		
	On the Way*	
		Up

Commander	Gunner	Loader
	Range	
Range-in**		
	On the Way*	
		Up
	Range	
Range-in**		
	On the Way*	
		Up
	Range	
Range-in**		
	On the Way*	
Cease Fire		

9. Determine the sensitivity of the muzzle position to weight on the muzzle. (Do this during Phase I.)

a. Aim the V-block telescope at the center of the grid board with the muzzle telescope in the muzzle.

b. Record the direction of the muzzle telescope.

c. Add weights of approximately 2.5, 5, 7.5, and 10 times the weight of the muzzle telescope to the muzzle of the gun. (Record weights used.) Check the aim of the V-block telescope after adding each weight and read the position of the muzzle telescope.

10. Poles to mark target positions on the moving target course shall be set up at 50 meter intervals starting at the north end of the N-S straight leg of the course. Every second pole should have a distinguishing symbol:
□, ○, △, ▽, etc.

*The gunner should announce "On the Way" as he inserts the lead so that the command will not delay the firing.
**Commander will take control to insert range and return control to gunner immediately prior to announcing range.

11. Each time a camera is loaded, the location of the frame at exposure relative to the timing mark is to be recorded.

B.2 EDT Plan for MICV-65 with All Electric Gun Drives

SECOND DRAFT OF ENGINEER DESIGN TEST PLAN FOR MICV-65 GENERAL ELECTRIC STABILIZATION SYSTEM TO VALIDATE HITPRO II

MAY 1972

RESEARCH DIRECTORATE
WEAPONS LABORATORY AT ROCK ISLAND
U. S. ARMY WEAPONS COMMAND
ROCK ISLAND, ILLINOIS

TABLE OF CONTENTS

SECTION 1 - INTRODUCTION

1.1 Project Identification

1.2 Test Objectives

The objective of this test is to collect critical data in order to verify and refine the HITPRO II math model for the MICV-65 with all electric gun stabilization.

1.3 Purpose of Test Plan

The purpose of this plan is to provide a viable guide to achieving the test objectives. Proposed changes or modification should be coordinated with either C. Alan Burnham or Captain John (NMI) Mandzy, autovon 793-5123 (commercial 309-794-5123) alternate extensions are 4116 or 4260.

SECTION 2 - RESPONSIBILITY

2.1 USAWECOM (SWERR-R) will:

a. assign one/two field engineer(s) for the duration of the test.

b. have responsibility for all tests conducted under this plan.

c. retain all collected data.

d. reduce and analyze the data.

e. provide film for gun camera and target camera.

f. provide the magnetic tape recorder and the tapes.

g. prepare the final test report.

h. provide bumps for the bump courses.

2.2 AMCPM-VRF will:

a. supply TP-T ammunition to be used for the test runs.

b. provide to SWERR-R any results obtained from the Techniques of Fire testing which would help to define items under the firing procedures (Section 3.3).

c. provide the Singer system for sensing projectile impact if found to be suitable.

2.3 Yakima Firing Center (in conjunction with Ft. Lewis) will:

a. provide an appropriate vehicle for use at the firing center by the WECOM field engineer(s) from 1 July through 1 December 1972.

b. construct necessary courses (Appendix C) for moving vehicle/moving target test runs.

c. survey all test courses to be used.

2.4 Paccar will:

a. assign one engineer and a back-up engineer (as needed) to the test.

b. assign one/two driver/mechanics as required to the test.

c. maintain the vehicle and gun, providing spare parts as needed. (These parts may have to be replaced at a later date.)

d. train the gunners to be used for the test.

e. supply, install, calibrate, operate and maintain both the gun and target cameras.

f. pre-expose two "light points" on the gun camera film and develop the film from both cameras.

g. make provision for recording a light "blip" on the gun camera film at the instant of trigger pull.

h. supply, set-up, record and maintain two anemometers for continuous recording of wind direction and magnitude.

i. provide capability for accurately measuring, recording and controlling the moving target velocity.

j. construct and maintain all targets.

k. construct and maintain any necessary down-range bunkers for personnel or equipment assuring that appropriate safety requirements are met.

l. provide and maintain two flood lights on the front of the targets for improving film data reduction and any lights required to illuminate the target for impact recognition by camera.

m. install bumps per SWERR-R direction.

2.5 General Electric will:

a. assign one technician to install and checkout the instrumentation to be recorded on magnetic tape and operate the instrumentation for the duration of the test.

b. assign one engineer to install and checkout the instrumentation.

c. assign one engineer on an as-required basis for maintenance during the test.

d. have overall responsibility for coordinating all recorded data in such a fashion as to insure that all data is time referenced.

e. make recommendations for methods of recording camera data, meteorological data, and target/round impact data.

f. provide, install, calibrate, maintain and operate all vehicle instrumentation other than the gun camera, and record the data on the magnetic tape recorder provided by SWERR-R.

g. maintain gun drive stabilization system.

h. provide a visual display capability such that recorded data may be displayed either during a run or immediately following the test run.

2.6 Points of Contact: See Appendix B.

SECTION 3 - DETAILS OF TEST

3.1 Description of Test Bed

The test bed will consist of a MICV-65 with the General Electric all electric optimum-ratio stabilization and gun control system. The vehicle mounts the M139 20MM automatic cannon and will fire TP-T ammunition for this test.

3.2 Description of Test Range (Range #15)

3.2.1 Stationary Target Tests

All stationary target tests will be done with the vehicle on the abandoned air strip. The air strip is essentially a hard-stand area where two straight perpendicular courses will be marked off and a curved course layed out. The desired target ranges can be obtained.

3.2.2 Moving Target Tests

In order to have moving vehicle/moving target tests construction of two straight vehicle courses is required. The moving target is constrained to a maximum size of approximately 12' x 12'. The maximum firing range for the moving target is approximately 750 meters. The target will move at the same velocity (approximately 10 MPH) for all moving target runs.

3.3 Firing Procedure

3.3.1 All test runs will be of sufficient length to permit firing of five bursts.

3.3.2 The burst length(s) and rate(s) of fire to be employed will be defined by Techniques of Fire Testing. The proposed schedule of test conditions (Appendix A) is based on one burst length and one rate of fire.

3.3.3 Two different types of gunner are desired for the test.

a. A skilled gunner with stabilized firing experience.

b. A skilled gunner with no stabilized firing experience.

3.4 Instrumentation and Data Collection

3.4.1 Instrumentation alignment and calibration shall be checked at the discretion of the WECOM field engineer.

3.4.2 Magnetic Tape Data Items

Data items a-r will be instrumented. Items s-y will be instrumented if feasible and may require more than one channel.

a. Voice Channel

b. Side-Side Acceleration

c. Fore-Aft Acceleration

d. Vertical Acceleration

e. Vehicle Velocity

f. Trigger Pull Pulse

g. Timing Channel

h. Elevation Motor Current

i. Traverse Motor Current

j. Elevation Relative Position

k. Traverse Relative Position

l. Elevation Relative Velocity

m. Traverse Relative Velocity

n. Elevation Gyro

o. Traverse Gyro

p. Vertical Gyro

q. Elevation Gunner Input

r. Traverse Gunner Input

s. Gun Recoil

t. Gun Recoil Force

u. Elevation Barrel Whip

v. Traverse Barrel Whip

w. Backlash

x. Shaft Wind-up

y. Structural Flexure

3.4.3 Film Data

a. Gun-mounted camera using film with pre-exposed light points.

b. Target camera to record location and order of round impacts.

3.4.4 Other Data Items

a. The Singer system for recording round impact and order will be used if feasible. This system will minimize use of target camera required under Sections 3.4.3 b.

b. Two anemometers will be used, one approximately at the target and one near the vehicle. The wind direction will also be recorded at both locations.

3.5 Description of Targets

3.5.1 Stationary Targets

All stationary targets will be 20' x 20' with one-foot grids. The center will be marked by a 7 1/2' x 7 1/2' cross.

3.5.2 Moving Targets

All moving targets will be 12' x 12' with one-foot grids. The center will be marked by a 7 1/2' x 7 1/2' cross.

SECTION 4 - TEST SCHEDULE

4.1 Dates of Tests

The vehicle is required for instrumentation by 18 September 1972 and under no circumstances later than 2 October 1972. Testing will be completed no later than 30 November 1972.

4.2 Overtime

Overtime will be used at the discretion of the WECOM field engineer for weekends and regular work-days.

TABLE B-1 PROPOSED SCHEDULE OF TEST CONDITIONS

NO. Of RUNS	COURSE(S)	VEHICLE SPEED(S)	VEHICLE DIRECTION (S)	TARGET SPEED(S)	TYPE OF GUNNER	RANGE(S) (METERS)	STABILIZATION MODE
12	--------	STATIONARY	-------	STATIONARY	STAB. EXPERIENCE EXPERIENCED	500 1000 1500	OFF ON
48	SMOOTH BUMP	5 MPH 10 MPH 20 MPH	CLOSING WITH TARGET PERPENDICULAR TO L.O.S.	STATIONARY	STAB. EXPERIENCE EXPERIENCED	500 1000	ON
12	CURVED	5 MPH 10 MPH 20 MPH	--------	STATIONARY	STAB. EXPERIENCE EXPERIENCED	500 1000	ON
8	-------	STATIONARY	-------	10 MPH	STAB. EXPERIENCE EXPERIENCED	500 750	OFF ON
24	SMOOTH BUMP	5 MPH 10 MPH 20 MPH	CLOSING WITH TARGET PERPENDICULAR TO L.O.S.	10 MPH	STAB. EXPERIENCE EXPERIENCED	700	ON

APPENDIX C - MOVING VEHICLE TEST COURSES ON MOVING TARGET RANGE

Two courses (one running at the target, one parallel to target) are required. They are to be 18 feet wide and approximately 300 meters long. Range to moving target is to be approximately 750 meters maximum. The courses must be sufficiently firm such that repeated runs over the course will not alter them appreciably. For some of the test runs, WECOM metal bumps will be set on the courses. The course must not allow these bumps to settle.

C.1 Digital Tapes

The M60A1E2 data is on several digital tapes at the AMC MIDWEST S & E Computer Center at AVSCOM (St. Louis). Some of the tapes were in poor condition and portions are not readable, thus, the data base in incomplete. The master tape indexes, Figures C-2 and C-3 list the data which is readable. These tables are arranged in order of increasing run number and channel number. Note that if a run and/or channel number does not appear in the index, the data is either lost or not readable. Table C-2 lists the test conditions for all run numbers, and these correspond to the run numbers in Figures C-2 and C-3. The tapes are 7-track, no-label form. Since this format is not convenient to use, the following program has been written to copy the data to a 9-track standard label tape:

```
//MP3C1BAD JOB (2T02,M127,1,2),'TAPE7 TO TAPE9'
/*SETUP             TM0090,TM0181
/*MESSAGE           PUT WRITE RING IN TM0090
//STEP EXEC PL1LFCLG,REGION=110K
//SYSIN DD *
 GRAB:  PROC OPTIONS(MAIN);
        DCL TAPE FILE INPUT, (DUMP,TAPE1) FILE OUTPUT;
        DCL RECORD CHAR(128), HEADER CHAR(13);
        ON ENDFILE(TAPE) GO TO CLOSE;
     GET FILE(SYSIN) EDIT(HEADER)(A(13));
 S1: GET FILE(TAPE) EDIT(RECORD)(A(128));
     IF SUBSTR(RECORD,1,3)='RUN' THEN GO TO S2; ELSE GO TO S1;
 S2: IF SUBSTR(RECORD,1,13)=HEADER THEN GO TO READ1;
     GET SKIP(190) FILE(TAPE);
     GO TO S1;
 READ1: PUT FILE(DUMP) EDIT(RECORD)(A);
        PUT FILE(TAPE1) EDIT(RECORD)(A);
 S3: DO I=1 TO 189;
     GET FILE(TAPE) EDIT(RECORD)(A(128));
     PUT FILE(DUMP) EDIT(RECORD)(A);
     PUT FILE(TAPE1) EDIT(RECORD)(A);
 END S3;
 CLOSE: PUT FILE(DUMP) EDIT('END OF RUN')(A);
        CLOSE FILE(TAPE1);
        CLOSE FILE(TAPE);
 END GRAB;
//GO.SYSIN DD *
RUN  15 CH   9
//DUMP DD SYSOUT=A,DCB=(RECFM=FB,LRECL=128,BLKSIZE=1280)
//TAPE DD UNIT=TAPE7,LABEL=(1,NL),DISP=(OLD,KEEP),VOL=SER=TM0181,
//       DCB=(LRECL=128,BLKSIZE=128,RECFM=FB,DEN=2,TRTCH=ET)
//TAPE1 DD UNIT=TAPE9,DISP=(NEW,KEEP),VOL=SER=TM0090,
//       DCB=(RECFM=FB,LRECL=128,BLKSIZE=1280),
//       DSN=RN15CH09,LABEL=(29,SL)
```

MICV - 65 COMBAT VEHICLE HITPRO II EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #
5	2	TM0336	1	8	15	TM0336	517	21	8	TM0336	331	24	20	TM0336	207
5	3	TM0337	257	8	16	TM0337	197	21	9	TM0337	459	24	21	TM0337	399
5	4	TM0336	129	8	17	TM0336	581	21	10	TM0337	75	65	2	TM0336	25
5	5	TM0337	1	8	18	TM0336	69	21	11	TM0336	395	65	3	TM0337	281
5	7	TM0336	257	8	19	TM0337	325	21	12	TM0337	139	65	4	TM0336	153
5	8	TM0336	321	8	20	TM0336	197	21	13	TM0336	459	65	5	TM0337	25
5	9	TM0337	449	8	21	TM0337	389	21	14	TM0337	523	65	7	TM0336	281
5	10	TM0337	65	9	2	TM0336	7	21	15	TM0336	523	65	8	TM0336	345
5	11	TM0336	358	9	3	TM0337	263	21	16	TM0337	203	65	9	TM0337	473
5	12	TM0337	129	9	4	TM0336	135	21	17	TM0336	587	65	10	TM0337	89
5	13	TM0336	449	9	5	TM0337	7	21	18	TM0336	75	65	11	TM0336	409
5	14	TM0337	513	9	7	TM0336	263	21	19	TM0337	331	65	12	TM0337	153
5	15	TM0336	513	9	8	TM0336	327	21	20	TM0336	203	65	13	TM0336	473
5	16	TM0337	193	9	9	TM0337	455	21	21	TM0337	395	65	14	TM0337	537
5	17	TM0336	577	9	10	TM0337	71	23	2	TM0336	13	65	15	TM0336	537
5	18	TM0336	65	9	11	TM0336	391	23	3	TM0337	269	65	16	TM0337	217
5	19	TM0337	321	9	12	TM0337	135	23	4	TM0336	141	65	17	TM0336	601
5	20	TM0336	193	9	13	TM0336	455	23	5	TM0337	13	65	18	TM0336	89
5	21	TM0337	354	9	14	TM0337	519	23	7	TM0336	269	65	19	TM0337	345
6	2	TM0335	3	9	15	TM0336	519	23	8	TM0336	333	65	20	TM0336	217
6	3	TM0337	259	9	16	TM0337	199	23	9	TM0337	461	65	21	TM0337	409
6	4	TM0336	131	9	17	TM0336	583	23	10	TM0337	77	66	2	TM0336	27
6	5	TM0337	3	9	18	TM0336	71	23	11	TM0336	397	66	3	TM0337	283
6	7	TM0336	259	9	19	TM0337	327	23	12	TM0337	141	66	4	TM0336	155
6	8	TM0336	323	9	20	TM0336	199	23	13	TM0336	461	66	5	TM0337	27
6	9	TM0337	451	9	21	TM0337	391	23	14	TM0337	525	66	7	TM0336	283
6	10	TM0337	67	20	2	TM0336	9	23	15	TM0336	525	66	8	TM0336	347
6	11	TM0336	387	20	3	TM0337	265	23	16	TM0337	205	66	9	TM0337	475
6	12	TM0337	131	20	4	TM0336	137	23	17	TM0336	589	66	10	TM0337	91
6	13	TM0336	451	20	5	TM0337	9	23	18	TM0336	77	66	11	TM0336	411
6	14	TM0337	515	20	7	TM0336	265	23	19	TM0337	333	66	12	TM0337	155
6	15	TM0336	515	20	8	TM0336	329	23	20	TM0336	205	66	13	TM0336	475
6	16	TM0337	195	20	9	TM0337	457	23	21	TM0337	397	66	14	TM0337	539
6	17	TM0336	579	20	10	TM0337	73	24	2	TM0336	15	66	15	TM0336	539
6	18	TM0336	67	20	11	TM0336	393	24	3	TM0337	271	66	16	TM0337	219
6	19	TM0337	323	20	12	TM0337	137	24	4	TM0336	143	66	17	TM0336	603
6	20	TM0336	195	20	13	TM0336	457	24	5	TM0337	15	66	18	TM0336	91
6	21	TM0337	387	20	14	TM0337	521	24	7	TM0336	271	66	19	TM0337	347
8	2	TM0336	5	20	15	TM0336	521	24	8	TM0336	335	66	20	TM0336	219
8	3	TM0337	261	20	16	TM0337	201	24	9	TM0337	463	66	21	TM0337	411
8	4	TM0336	133	20	17	TM0336	585	24	10	TM0337	79	68	2	TM0336	29
8	5	TM0337	5	20	18	TM0336	73	24	11	TM0336	399	68	3	TM0337	285
8	7	TM0336	261	20	19	TM0337	329	24	12	TM0337	143	68	4	TM0336	157
8	8	TM0336	325	20	20	TM0336	201	24	13	TM0336	463	68	5	TM0337	29
8	9	TM0337	453	20	21	TM0337	393	24	14	TM0337	527	68	7	TM0336	285
8	10	TM0337	69	21	2	TM0336	11	24	15	TM0336	527	68	8	TM0336	349
8	11	TM0336	389	21	3	TM0337	267	24	16	TM0337	207	68	9	TM0337	479
8	12	TM0337	133	21	4	TM0336	139	24	17	TM0336	591	68	10	TM0337	93
8	13	TM0336	453	21	5	TM0337	19	24	18	TM0336	79	68	11	TM0336	413
8	14	TM0337	517	21	7	TM0336	267	24	19	TM0337	335	68	12	TM0337	157

Figure C-1

MICV - 65 COMBAT VEHICLE HITPRO II EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	DS #
68	13	TM0336	477
68	14	TM0337	543
68	15	TM0336	541
68	16	TM0337	221
68	17	TM0336	605
68	18	TM0336	93
68	19	TM0337	349
68	20	TM0336	221
68	21	TM0337	413
69	2	TM0336	31
69	3	TM0337	287
69	4	TM0336	159
69	5	TM0337	31
69	7	TM0336	287
69	8	TM0336	351
69	9	TM0337	479
69	10	TM0337	95
69	11	TM0336	415
69	12	TM0337	159
69	13	TM0336	479
69	14	TM0337	543
69	15	TM0336	543
69	16	TM0337	223
69	17	TM0336	607
69	18	TM0336	95
69	19	TM0337	351
69	20	TM0336	223
69	21	TM0337	415
78	2	TM0336	17
78	3	TM0337	273
78	4	TM0336	145
78	5	TM0337	17
78	7	TM0336	273
78	8	TM0336	337
78	9	TM0337	465
78	10	TM0337	81
78	11	TM0336	401
78	12	TM0337	145
78	13	TM0336	465
78	14	TM0337	529
78	15	TM0336	529
78	16	TM0337	207
78	17	TM0336	593
78	18	TM0336	81
78	19	TM0337	337
78	20	TM0336	279
78	21	TM0337	401
80	2	TM0336	19
80	3	TM0337	275
80	4	TM0336	147

RUN	CHANNEL	TAPE #	DS #
80	5	TM0337	19
80	7	TM0336	275
80	8	TM0336	339
80	9	TM0337	467
80	10	TM0337	83
80	11	TM0336	403
80	12	TM0337	147
80	13	TM0336	407
80	14	TM0337	531
80	15	TM0336	531
80	16	TM0337	211
80	17	TM0336	595
80	18	TM0336	83
80	19	TM0337	339
80	20	TM0336	211
80	21	TM0337	403
81	2	TM0336	21
81	3	TM0337	277
81	4	TM0336	149
81	5	TM0337	21
81	7	TM0336	277
81	8	TM0336	341
81	9	TM0337	469
81	10	TM0337	85
81	11	TM0336	405
81	12	TM0337	149
81	13	TM0336	469
81	14	TM0337	533
81	15	TM0336	533
81	16	TM0337	213
81	17	TM0336	597
81	18	TM0336	85
81	19	TM0337	341
81	20	TM0336	213
81	21	TM0337	405
84	2	TM0336	23
84	3	TM0337	279
84	4	TM0336	151
84	5	TM0337	23
84	7	TM0336	279
84	8	TM0336	343
84	9	TM0337	471
84	10	TM0337	87
84	11	TM0336	407
84	12	TM0337	151
84	13	TM0336	471
84	14	TM0337	535
84	15	TM0336	535
84	16	TM0337	215
84	17	TM0336	599

RUN	CHANNEL	TAPE #	DS #
84	18	TM0336	87
84	19	TM0337	343
84	20	TM0336	215
84	21	TM0337	407
93	2	TM0336	33
93	3	TM0337	289
93	4	TM0336	161
93	5	TM0337	33
93	7	TM0336	289
93	8	TM0336	353
93	9	TM0337	481
93	10	TM0337	97
93	11	TM0336	417
93	12	TM0337	161
93	13	TM0336	481
93	14	TM0337	545
93	15	TM0336	545
93	16	TM0337	225
93	17	TM0336	609
93	18	TM0336	97
93	19	TM0337	353
93	20	TM0336	225
93	21	TM0337	417
95	2	TM0336	35
95	3	TM0337	291
95	4	TM0336	163
95	5	TM0337	35
95	7	TM0336	291
95	8	TM0336	355
95	9	TM0337	483
95	10	TM0337	99
95	11	TM0336	419
95	12	TM0337	163
95	13	TM0336	483
95	14	TM0337	547
95	15	TM0336	547
95	16	TM0337	227
95	17	TM0336	611
95	18	TM0336	99
95	19	TM0337	355
95	20	TM0336	227
95	21	TM0337	419
96	2	TM0336	37
96	3	TM0337	293
96	4	TM0336	165
96	5	TM0337	37
96	7	TM0336	293
96	8	TM0336	357
96	9	TM0337	485
96	10	TM0337	101

RUN	CHANNEL	TAPE #	DS #
96	11	TM0336	421
96	12	TM0337	165
96	13	TM0336	485
96	14	TM0337	549
96	15	TM0336	549
96	16	TM0337	229
96	17	TM0336	613
96	18	TM0336	101
96	19	TM0337	357
96	20	TM0336	229
96	21	TM0337	421
98	2	TM0336	39
98	3	TM0337	295
98	4	TM0336	167
98	5	TM0337	39
98	7	TM0336	295
98	8	TM0336	359
98	9	TM0337	487
98	10	TM0337	103
98	11	TM0336	423
98	12	TM0337	167
98	13	TM0336	487
98	14	TM0337	551
98	15	TM0336	551
98	16	TM0337	231
98	17	TM0336	615
98	18	TM0336	103
98	19	TM0337	359
98	20	TM0336	231
98	21	TM0337	423
108	2	TM0336	41
108	3	TM0337	297
108	4	TM0336	169
108	5	TM0337	41
108	7	TM0336	297
108	8	TM0336	361
108	9	TM0337	489
108	10	TM0337	105
108	11	TM0336	425
108	12	TM0337	169
108	13	TM0336	489
108	14	TM0337	553
108	15	TM0336	553
108	16	TM0337	233
108	17	TM0336	617
108	18	TM0336	105
108	19	TM0337	361
108	20	TM0336	233
108	21	TM0337	425
110	2	TM0336	43

Figure C-1 (cont'd)

MICV - 65 COMBAT VEHICLE HITPRO II EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #
110	3	TM0337	299	114	16	TM0337	239	129	9	TM0337	501	137	21	TM0337	441
110	4	TM0336	171	114	17	TM0336	623	129	10	TM0337	117	138	2	TM0336	59
110	5	TM0337	43	114	18	TM0336	111	129	11	TM0336	437	138	3	TM0337	315
110	7	TM0336	299	114	19	TM0337	367	129	12	TM0337	181	138	4	TM0336	187
110	8	TM0336	363	114	20	TM0336	239	129	13	TM0336	501	138	5	TM0337	59
110	9	TM0337	491	114	21	TM0337	431	129	14	TM0337	565	138	7	TM0336	315
110	10	TM0337	107	125	2	TM0336	49	129	15	TM0336	565	138	8	TM0336	379
110	11	TM0336	427	125	3	TM0337	305	129	16	TM0337	245	138	9	TM0337	507
110	12	TM0337	171	125	4	TM0336	177	129	17	TM0336	631	138	10	TM0337	123
110	13	TM0336	491	125	5	TM0337	49	129	18	TM0336	117	138	11	TM0336	443
110	14	TM0337	555	125	7	TM0336	305	129	19	TM0337	373	138	12	TM0337	187
110	15	TM0336	555	125	8	TM0336	369	129	20	TM0336	245	138	13	TM0336	507
110	16	TM0337	235	125	9	TM0337	497	129	21	TM0337	437	138	14	TM0337	569
110	17	TM0336	619	125	10	TM0337	113	131	2	TM0336	55	138	15	TM0336	569
110	18	TM0336	107	125	11	TM0336	433	131	3	TM0337	311	138	16	TM0337	251
110	19	TM0337	363	125	12	TM0337	177	131	4	TM0336	183	138	17	TM0336	637
110	20	TM0336	235	125	13	TM0336	497	131	5	TM0337	55	138	18	TM0336	123
110	21	TM0337	427	125	14	TM0337	561	131	7	TM0336	311	138	19	TM0337	379
111	2	TM0336	45	125	15	TM0336	561	131	8	TM0336	375	138	20	TM0336	251
111	3	TM0337	301	125	16	TM0337	241	131	9	TM0337	503	138	21	TM0337	443
111	4	TM0336	173	125	17	TM0336	625	131	10	TM0337	119	139	2	TM0336	61
111	5	TM0337	45	125	18	TM0336	113	131	11	TM0336	439	139	3	TM0337	317
111	7	TM0336	301	125	19	TM0337	369	131	12	TM0337	183	139	4	TM0336	189
111	8	TM0336	365	125	20	TM0336	241	131	13	TM0336	503	139	5	TM0337	61
111	9	TM0337	493	125	21	TM0337	433	131	14	TM0337	567	139	7	TM0336	317
111	10	TM0337	109	126	2	TM0336	51	131	15	TM0336	567	139	8	TM0336	381
111	11	TM0336	429	126	3	TM0337	307	131	16	TM0337	247	139	9	TM0337	509
111	12	TM0337	173	126	4	TM0336	179	131	1·	TM0336	633	139	10	TM0337	125
111	13	TM0336	493	126	5	TM0337	51	131	18	TM0336	119	139	11	TM0336	445
111	14	TM0337	557	126	7	TM0336	307	131	19	TM0337	375	139	12	TM0337	189
111	15	TM0336	557	126	8	TM0336	371	131	20	TM0336	247	139	13	TM0336	509
111	16	TM0337	237	126	9	TM0337	499	131	21	TM0337	439	139	14	TM0337	571
111	17	TM0336	621	126	10	TM0337	115	137	2	TM0336	57	139	15	TM0336	573
111	18	TM0336	109	126	11	TM0336	435	137	3	TM0337	313	139	16	TM0337	253
111	19	TM0337	365	126	12	TM0337	179	137	4	TM0336	185	139	17	TM0336	639
111	20	TM0336	237	126	13	TM0336	499	137	5	TM0337	57	139	18	TM0336	125
111	21	TM0337	429	126	14	TM0337	563	137	7	TM0336	313	139	19	TM0337	381
114	2	TM0336	47	126	15	TM0336	563	137	8	TM0336	377	139	20	TM0336	253
114	3	TM0337	203	126	16	TM0337	243	137	9	TM0337	505	139	21	TM0337	445
114	4	TM0336	175	126	17	TM0336	629	137	10	TM0337	121	141	2	TM0336	63
114	5	TM0337	47	126	18	TM0336	115	137	11	TM0336	441	141	3	TM0337	319
114	7	TM0336	203	126	19	TM0337	371	137	12	TM0337	185	141	4	TM0336	191
114	8	TM0336	367	126	20	TM0336	243	137	13	TM0336	505	141	5	TM0337	63
114	9	TM0337	495	126	21	TM0337	435	137	14	TM0337	567	141	7	TM0336	319
114	10	TM0337	111	129	2	TM0336	53	137	15	TM0336	569	141	8	TM0336	383
114	11	TM0336	431	129	3	TM0337	309	137	16	TM0337	249	141	9	TM0337	511
114	12	TM0337	175	129	4	TM0336	121	137	17	TM0336	635	141	10	TM0337	127
114	13	TM0336	495	129	5	TM0337	53	137	18	TM0336	121	141	11	TM0336	447
114	14	TM0337	559	129	7	TM0336	309	137	19	TM0337	377	141	12	TM0337	191
114	15	TM0336	559	129	8	TM0336	373	137	20	TM0336	249	141	13	TM0336	511

Figure C-1 (cont'd)

MICV - 65 COMBAT VEHICLE HITPRO II EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #	RUN	CHANNEL	TAPE #	DS #
141	14	TM0337	573	141	16	TM0337	255	141	18	TM0336	127	141	20	TM0336	255
141	15	TM0336	573	141	17	TM0336	641	141	19	TM0337	383	141	21	TM0337	477

Figure C-1 (cont'd)

M60A1E2 TANK S/N 5511(ET#1) HITPHO EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #
21	1	TM0037	67	6	TM0037	69	5	TM0037	70	3	TM0037
21	2	TM0037	67	7	TM0037	69	6	TM0037	70	4	TM0037
21	3	TM0037	67	8	TM0037	69	7	TM0037	70	5	TM0037
21	4	TM0037	67	9	TM0037	69	8	TM0037	70	6	TM0037
21	5	TM0037	67	10	TM0037	69	9	TM0037	70	7	TM0037
21	6	TM0037	67	11	TM0037	69	10	TM0037	70	8	TM0037
67	1	TM0037	67	12	TM0037	69	11	TM0037	70	9	TM0037
67	2	TM0037	69	1	TM0037	69	12	TM0037	70	10	TM0037
67	3	TM0037	69	2	TM0037	70	1	TM0037	70	11	TM0037
67	4	TM0037	69	3	TM0037	70	2	TM0037	70	12	TM0037
67	5	TM0037	69	4	TM0037						

Figure C-2 G.E. Data

M60A1E2 TANK S/N 5511(E1#1) HIPRO EVALUATION TEST D TA
MASTER APE INDEX

RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #
2	1	TM0041	5	7	TM0515	10	13	TM0041	13	21	TM0039
2	2	TM0041	5	8	TM0515	10	20	TM0041	13	22	TM0039
2	3	TM0041	5	9	TM0515	10	21	TM0041	13	23	TM0039
2	4	TM0041	5	10	TM0515	10	22	TM0041	13	27	TM0039
2	5	TM0041	5	11	TM0515	10	23	TM0041	14	1	TM0041
2	6	TM0041	5	12	TM0515	10	24	TM0041	14	2	TM0041
2	7	TM0041	5	13	TM0515	10	25	TM0041	14	3	TM0041
2	8	TM0041	5	20	TM0515	10	26	TM0041	14	4	TM0041
2	9	TM0041	5	21	TM0515	10	27	TM0041	14	5	TM0041
2	10	TM0041	5	22	TM0515	10	28	TM0041	14	6	TM0041
2	11	TM0041	5	23	TM0515	12	1	TM0041	14	7	TM0041
2	12	TM0041	5	24	TM0515	12	2	TM0041	14	8	TM0041
2	13	TM0041	5	25	TM0515	12	3	TM0041	14	9	TM0041
2	20	TM0041	5	26	TM0515	12	4	TM0041	14	10	TM0041
2	21	TM0041	5	27	TM0515	12	5	TM0041	14	11	TM0041
2	22	TM0041	5	28	TM0515	12	6	TM0041	14	12	TM0039
2	23	TM0041	8	1	TM0041	12	7	TM0041	14	13	TM0039
2	24	TM0041	8	2	TM0041	12	8	TM0041	14	14	TM0039
2	25	TM0041	8	3	TM0041	12	9	TM0041	14	15	TM0039
2	26	TM0041	8	4	TM0041	12	10	TM0041	14	16	TM0039
2	27	TM0041	8	5	TM0041	12	11	TM0041	14	17	TM0039
2	28	TM0041	8	6	TM0041	12	12	TM0041	14	18	TM0039
4	1	TM0041	8	7	TM0041	12	13	TM0041	14	19	TM0039
4	2	TM0041	8	8	TM0041	12	20	TM0041	14	20	TM0039
4	3	TM0041	8	9	TM0041	12	21	TM0041	14	21	TM0039
4	4	TM0041	8	10	TM0041	12	22	TM0041	14	22	TM0039
4	5	TM0041	8	11	TM0041	12	23	TM0041	14	23	TM0039
4	6	TM0041	8	12	TM0041	12	24	TM0041	14	24	TM0041
4	7	TM0041	8	13	TM0041	12	25	TM0041	14	25	TM0041
4	8	TM0041	8	20	TM0041	12	26	TM0041	14	26	TM0041
4	9	TM0041	8	21	TM0041	12	27	TM0041	14	27	TM0041
4	10	TM0041	8	22	TM0041	12	28	TM0041	14	28	TM0041
4	11	TM0041	8	23	TM0041	13	1	TM0039	15	1	TM0181
4	12	TM0041	8	24	TM0041	13	2	TM0039	15	2	TM0181
4	13	TM0041	8	25	TM0041	13	3	TM0039	15	3	TM0181
4	20	TM0041	8	26	TM0041	13	4	TM0039	15	4	TM0181
4	21	TM0041	8	27	TM0041	13	5	TM0039	15	5	TM0181
4	22	TM0041	8	28	TM0041	13	6	TM0039	15	6	TM0181
4	23	TM0041	10	1	TM0041	13	7	TM0039	15	7	TM0181
4	24	TM0041	10	2	TM0041	13	8	TM0039	15	8	TM0181
4	25	TM0041	10	3	TM0041	13	11	TM0039	15	9	TM0181
4	26	TM0041	10	4	TM0041	13	12	TM0039	15	10	TM0181
4	27	TM0041	10	5	TM0041	13	13	TM0039	15	11	TM0181
4	28	TM0041	10	6	TM0041	13	14	TM0039	15	12	TM0181
5	1	TM0515	10	7	TM0041	13	15	TM0039	15	13	TM0181
5	2	TM0515	10	8	TM0041	13	16	TM0039	15	14	TM0181
5	3	TM0515	10	9	TM0041	13	17	TM0039	15	15	TM0181
5	4	TM0515	10	10	TM0041	13	18	TM0039	15	16	TM0181
5	5	TM0515	10	11	TM0041	13	19	TM0039	15	17	TM0181
5	6	TM0515	10	12	TM0041	13	20	TM0039	15	18	TM0181

Figure C-3 CAD Gage Data

M60A1E2 TANK S/N 5511(EI#1) HIPRO EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #
15	19	TM0181
15	20	TM0181
15	21	TM0181
15	22	TM0181
15	23	TM0181
15	24	TM0181
15	25	TM0181
15	26	TM0181
15	27	TM0181
15	28	TM0181
16	1	TM0181
16	2	TM0181
16	3	TM0181
16	4	TM0181
16	5	TM0181
16	6	TM0181
16	7	TM0181
16	8	TM0181
16	9	TM0181
16	10	TM0181
16	11	TM0181
16	12	TM0181
16	13	TM0181
16	14	TM0181
16	15	TM0181
16	16	TM0181
16	17	TM0181
16	18	TM0181
16	19	TM0181
16	20	TM0181
16	21	TM0181
16	22	TM0181
16	23	TM0181
16	24	TM0181
16	25	TM0181
16	26	TM0181
16	27	TM0181
16	28	TM0181
18	1	TM0516
18	2	TM0516
18	3	TM0516
18	4	TM0516
18	5	TM0516
18	6	TM0516
18	7	TM0516
18	8	TM0516
18	9	TM0516
18	10	TM0516
18	11	TM0516
18	12	TM0516
18	13	TM0516
18	14	TM0516
18	15	TM0516
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18	17	TM0516
18	18	TM0516
18	19	TM0516
18	20	TM0516
18	21	TM0516
18	22	TM0516
18	23	TM0516
18	24	TM0516
18	25	TM0516
18	26	TM0516
18	27	TM0516
18	28	TM0516
19	1	TM0039
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19	4	TM0039
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19	7	TM0041
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20	28	TM0181
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23	12	TM0523
23	13	TM0523
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23	21	TM0523
23	22	TM0523
23	23	TM0523
24	14	TM0039
24	15	TM0039
24	16	TM0039
24	17	TM0039
24	18	TM0039
24	19	TM0039
25	1	TM0517
25	2	TM0523
25	3	TM0523
25	4	TM0523
25	5	TM0523
25	6	TM0523
25	7	TM0517
25	8	TM0517
25	9	TM0517
25	10	TM0517

Figure C-3 CAD Gage Data (cont'd)

M60A1E2 TANK S/N 5511(E1#1) HITPRO EVALUATION TES DATA
MAST · TAPE INDEX

RUN	CHANNEL	TAPE #
25	11	TM0517
25	12	TM0523
25	13	TM0523
25	20	TM0523
25	21	TM0523
25	22	TM0523
25	23	TM0523
26	14	TM0039
26	15	TM0039
26	16	TM0039
26	17	TM0039
26	18	TM0039
26	19	TM0039
27	1	TM0516
27	2	TM0516
27	3	TM0516
27	4	TM0516
27	5	TM0516
27	6	TM0516
27	7	TM0517
27	8	TM0517
27	9	TM0517
27	10	TM0517
27	11	TM0517
27	12	TM0523
27	13	TM0523
27	20	TM0523
27	21	TM052.
27	22	TM0523
27	23	TM0523
28	1	TM0181
28	2	TM0181
28	3	TM0181
28	4	TM0181
28	5	TM0181
28	6	TM0181
28	7	TM0181
28	8	TM0181
28	9	TM0181
28	10	TM0181
28	11	TM0181
28	12	TM0181
28	13	TM0181
28	14	TM0181
28	15	TM0181
28	16	TM0181
28	17	TM0181
28	18	TM0181
28	19	TM0181
28	20	TM0181

RUN	CHANNEL	TAPE #
28	21	TM0181
28	22	TM0181
28	23	TM0181
28	24	TM0181
28	25	TM0181
28	26	TM0181
28	27	TM0181
28	28	TM0181
29	1	TM0517
29	2	TM0523
29	3	TM0523
29	4	TM0523
29	5	TM0523
29	6	TM0523
29	7	TM0517
29	8	TM0517
29	9	TM0517
29	10	TM0517
29	11	TM0517
29	12	TM0523
29	13	TM0523
29	20	TM0523
29	21	TM0523
29	22	TM0523
29	23	TM0523
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30	2	TM0181
30	3	TM0181
30	4	TM0181
30	5	TM0181
30	6	TM0181
30	7	TM0180
30	8	TM0180
30	9	TM0180
30	10	TM0180
30	11	TM0180
30	12	TM0180
30	13	TM0181
30	14	TM0180
30	15	TM0180
30	16	TM0180
30	17	TM0180
30	18	TM0180
30	19	TM0180
30	20	TM0181
30	21	TM0181
30	22	TM0181
30	23	TM0181
30	24	TM0180
30	25	TM0180

RUN	CHANNEL	TAPE #
30	26	TM0180
30	27	TM0180
30	28	TM0180
31	14	TM0039
31	15	TM0039
31	16	TM0039
31	17	TM0039
31	18	TM0039
31	19	TM0039
32	13	TM0039
32	14	TM0039
32	15	TM0039
32	16	TM0039
32	17	TM0039
32	18	TM0039
32	19	TM0039
32	20	TM0039
32	21	TM0039
32	22	TM0039
32	23	TM0039
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33	14	TM0039
33	15	TM0039
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34	16	TM0039
34	17	TM0039
34	18	TM0039
34	19	TM0039
34	20	TM0039
34	21	TM0039
34	22	TM0039
34	23	TM0039
35	1	TM0180
35	2	TM0180
35	3	TM0180
35	4	TM0180
35	5	TM0180
35	6	TM0180

RUN	CHANNEL	TAPE #
35	7	TM0180
35	8	TM0180
35	9	TM0180
35	10	TM0180
35	11	TM0180
35	12	TM0180
35	13	TM0180
35	14	TM0180
35	15	TM0180
35	16	TM0180
35	17	TM0180
35	18	TM0180
35	19	TM0180
35	20	TM0180
35	21	TM0180
35	22	TM0180
35	23	TM0180
35	24	TM0180
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35	26	TM0180
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35	28	TM0180
36	1	TM0180
36	2	TM0180
36	3	TM0180
36	4	TM0180
36	5	TM0180
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36	7	TM0180
36	8	TM0180
36	9	TM0180
36	10	TM0180
36	11	TM0180
36	12	TM0180
36	13	TM0180
36	14	TM0180
36	15	TM0180
36	16	TM0180
36	17	TM0180
36	18	TM0180
36	19	TM0180
36	20	TM0180
36	21	TM0180
36	22	TM0180
36	23	TM0180
36	24	TM0180
36	25	TM0180
36	26	TM0180
36	27	TM0180
36	28	TM0180

Figure C-3 CAD Gage Data (cont'd)

M60A1E2 TANK S/N 5511(EI#1) HIIPRO EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #
37	1	TM0180	38	23	TM0180	48	22	TM0524	52	13	TM0524
37	2	TM0180	38	24	TM0180	48	23	TM0524	52	20	TM0524
37	3	TM0180	38	25	TM0180	49	1	TM0524	52	21	TM0524
37	4	TM0180	38	26	TM0180	49	2	TM0524	52	22	TM0524
37	5	TM0180	38	27	TM0180	49	3	TM0524	52	23	TM0524
37	6	TM0180	38	28	TM0180	49	4	TM0524	53	1	TM0524
37	7	TM0180	44	1	TM0515	49	5	TM0524	53	2	TM0524
37	8	TM0180	44	2	TM0521	49	6	TM0524	53	3	TM0524
37	9	TM0180	44	3	TM0521	49	12	TM0524	53	4	TM0524
37	10	TM0180	44	4	TM0521	49	13	TM0524	53	5	TM0524
37	11	TM0180	44	5	TM0521	49	20	TM0524	53	6	TM0524
37	12	TM0180	44	6	TM0521	49	21	TM0524	54	1	TM0524
37	13	TM0180	44	7	TM0515	49	22	TM0524	54	2	TM0524
37	14	TM0180	44	8	TM0515	49	23	TM0524	54	3	TM0524
37	15	TM0180	44	9	TM0515	50	1	TM0524	54	4	TM0524
37	16	TM0180	44	10	TM0515	50	2	TM0524	54	5	TM0524
37	17	TM0180	44	11	TM0515	50	3	TM0524	54	6	TM0524
37	18	TM0180	44	12	TM0515	50	4	TM0524	54	12	TM0521
37	19	TM0180	44	24	TM0515	50	5	TM0524	54	24	TM0521
37	20	TM0180	44	25	TM0515	50	6	TM0524	54	25	TM0521
37	21	TM0180	44	26	TM0515	50	12	TM0524	54	26	TM0521
37	22	TM0180	44	27	TM0515	50	13	TM0524	54	27	TM0521
37	23	TM0180	44	28	TM0515	50	20	TM0524	54	28	TM0521
37	24	TM0180	46	1	TM0515	50	21	TM0524	55	1	TM0521
37	25	TM0180	46	2	TM0521	50	22	TM0524	55	2	TM0521
37	26	TM0180	46	3	TM0521	50	23	TM0524	55	3	TM0521
37	27	TM0180	46	4	TM0521	51	1	TM0521	55	4	TM0521
37	28	TM0180	46	5	TM0521	51	2	TM0524	55	5	TM0521
38	1	TM0180	46	6	TM0521	51	3	TM0524	55	6	TM0521
38	2	TM0180	46	7	TM0515	51	4	TM0524	55	12	TM0521
38	3	TM0180	46	8	TM0515	51	5	TM0524	55	24	TM0521
38	4	TM0180	46	9	TM0515	51	6	TM0524	55	25	TM0521
38	5	TM0180	46	10	TM0515	51	7	TM0521	55	26	TM0521
38	6	TM0180	46	11	TM0515	51	8	TM0521	55	27	TM0521
38	7	TM0180	46	12	TM0515	51	9	TM0521	55	28	TM0521
38	8	TM0180	46	24	TM0515	51	10	TM0521	56	1	TM0524
38	9	TM0180	46	25	TM0515	51	11	TM0521	56	2	TM0524
38	10	TM0180	46	26	TM0515	51	12	TM0524	56	3	TM0524
38	11	TM0180	46	27	TM0515	51	13	TM0524	56	4	TM0524
38	12	TM0180	46	28	TM0515	51	20	TM0524	56	5	TM0524
38	13	TM0180	48	1	TM0524	51	21	TM0524	56	6	TM0524
38	14	TM0180	48	2	TM0524	51	22	TM0524	56	12	TM0521
38	15	TM0180	48	3	TM0524	51	23	TM0524	56	24	TM0521
38	16	TM0180	48	4	TM0524	52	1	TM0524	56	25	TM0521
38	17	TM0180	48	5	TM0524	52	2	TM0524	56	26	TM0521
38	18	TM0180	48	6	TM0524	52	3	TM0524	56	27	TM0521
38	19	TM0180	48	12	TM0524	52	4	TM0524	56	28	TM0521
38	20	TM0180	48	13	TM0524	52	5	TM0524	57	1	TM0524
38	21	TM0180	48	20	TM0524	52	6	TM0524	57	2	TM0524
38	22	TM0180	48	21	TM0524	52	12	TM0524	57	3	TM0524

Figure C-3 CAD Gage Data (cont'd)

M60A1E2 TANK S/N 5511(ET#1) HITPRO EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #
57	4	TM0524
57	5	TM0524
57	6	TM0524
57	12	TM052.
57	24	TM0521
57	25	TM0521
57	26	TM0521
57	27	TM0521
57	28	TM0521
58	1	TM0524
58	2	TM0524
58	3	TM0524
58	4	TM0524
58	5	TM0524
58	6	TM0524
58	12	TM0521
58	24	TM0521
58	25	TM0521
58	26	TM0521
58	27	TM0521
58	28	TM0521
59	1	TM0524
5	2	TM0524
59	3	TM0524
59	4	TM0524
59	5	TM0524
59	6	TM0524
59	12	TM0521
59	14	TM0516
59	15	TM0516
59	16	TM0516
59	17	TM0516
59	18	TM0516
59	19	TM0516
59	24	TM0521
59	25	TM0521
59	26	TM0521
59	27	TM0521
59	28	TM0521
60	1	TM0521
60	2	TM0521
60	3	TM0521
60	4	TM0521
60	5	TM0521
60	6	TM0521
60	7	TM0521
60	8	TM0521
60	9	TM0521
60	10	TM0521
60	11	TM0521

RUN	CHANNEL	TAPE #
60	12	TM0521
60	14	TM0516
60	15	TM0516
60	16	TM0516
60	17	TM0516
60	18	TM0516
60	19	TM0516
60	24	TM0521
60	25	TM0521
60	26	TM0521
60	27	TM0521
60	28	TM0521
61	1	TM0524
61	2	TM0524
61	3	TM0524
61	4	TM0524
61	5	TM0524
61	6	TM0524
61	12	TM0521
61	14	TM0516
61	15	TM0516
61	16	TM0516
61	17	TM0516
61	18	TM0516
61	19	TM0516
61	24	TM0521
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61	26	TM0521
61	27	TM0521
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62	12	TM0515
62	13	TM0522
62	14	TM0523
62	15	TM0523
62	16	TM0523
62	17	TM0523
62	18	TM0523
62	19	TM0523
62	20	TM0522

RUN	CHANNEL	TAPE #
62	21	TM0522
62	22	TM0522
62	23	TM0522
62	24	TM0515
62	25	TM0515
62	26	TM0515
62	27	TM0515
62	28	TM0515
63	1	TM0522
63	2	TM0522
63	3	TM0522
63	4	TM0522
63	5	TM0522
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64	3	TM0522
64	4	TM0522
64	5	TM0522
64	6	TM0522
64	7	TM0522
64	8	TM0522
64	9	TM0522
64	10	TM0522
64	11	TM052.
64	12	TM0515
64	13	TM0522
64	14	TM0523

RUN	CHANNEL	TAPE #
64	15	TM0523
64	16	TM0523
64	17	TM0523
64	18	TM0523
64	19	TM0523
64	20	TM0522
64	21	TM0522
64	22	TM0522
64	23	TM0522
64	24	TM0515
64	25	TM0515
64	26	TM0515
64	27	TM0515
64	28	TM0515
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65	23	TM0522
65	24	TM0515
65	25	TM0515
65	26	TM0515
65	27	TM0515
65	28	TM0515
66	1	TM0522
66	2	TM0522
66	3	TM0522
66	4	TM0522
66	5	TM0522
66	6	TM0522
66	7	TM0522
66	8	TM0522

Figure C-3 CAD Gage Data (cont'd)

M60A1E2 TANK S/N 5511(ET#1) HIPRO EVALUATION TEST DATA
MASTER TAPE INDEX

RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #
66	9	TM0522	68	3	TM0516	69	25	TM0517	71	25	TM0515
66	10	TM0522	68	4	TM0516	69	26	TM0517	71	26	TM0515
66	11	TM0522	68	5	TM0516	69	27	TM0517	71	27	TM0515
66	12	TM0515	68	6	TM0516	69	28	TM0517	71	28	TM0515
66	13	TM0522	68	7	TM0517	70	1	TM0517	72	1	TM0522
66	14	TM0523	68	8	TM0517	70	2	TM0517	72	2	TM0522
66	15	TM0523	68	9	TM0517	70	3	TM0517	72	3	TM0522
66	16	TM0523	68	10	TM0517	70	4	TM0517	72	4	TM0522
66	17	TM0523	68	11	TM0517	70	5	TM0517	72	5	TM0522
66	18	TM0523	68	12	TM0517	70	6	TM0517	72	6	TM0522
66	19	TM0523	68	13	TM0517	70	7	TM0517	72	7	TM0515
66	20	TM0522	68	14	TM0523	70	8	TM0517	72	8	TM0515
66	21	TM0522	68	15	TM0523	70	9	TM0517	72	9	TM0515
66	22	TM0522	68	16	TM0523	70	10	TM0517	72	10	TM0515
66	23	TM0522	68	17	TM0523	70	11	TM0517	72	11	TM0515
66	24	TM0515	68	18	TM0523	70	12	TM0517	72	12	TM0515
66	25	TM0515	68	19	TM0523	70	13	TM0517	72	13	TM0522
66	26	TM0515	68	20	TM0517	70	14	TM0523	72	20	TM0522
66	27	TM0515	68	21	TM0517	70	15	TM0523	72	21	TM0522
66	28	TM0515	68	22	TM0517	70	16	TM0523	72	22	TM0522
67	1	TM0516	68	23	TM0517	70	17	TM0523	72	23	TM0522
67	2	TM0516	68	24	TM0517	70	18	TM0523	72	24	TM0515
67	3	TM0516	68	25	TM0517	70	19	TM0523	72	25	TM0515
67	4	TM0516	68	26	TM0517	70	20	TM0517	72	26	TM0515
67	5	TM0516	68	27	TM0517	70	21	TM0517	72	27	TM0515
67	6	TM0515	68	28	TM0517	70	22	TM0517	72	28	TM0515
67	7	TM0517	69	1	TM0517	70	23	TM0517	73	1	TM0515
67	8	TM0517	69	2	TM0517	70	24	TM0517	73	2	TM0522
67	9	TM0517	69	3	TM0517	70	25	TM0517	73	3	TM0522
67	10	TM0517	69	4	TM0517	70	26	TM0517	73	4	TM0522
67	11	TM0517	69	5	TM0517	70	27	TM0517	73	5	TM0522
67	12	TM0517	69	6	TM0517	70	28	TM0517	73	6	TM0522
67	13	TM0517	69	7	TM0517	71	1	TM0515	73	7	TM0515
67	14	TM0523	69	8	TM0517	71	2	TM0522	73	8	TM0515
67	15	TM0523	69	9	TM0517	71	3	TM0522	73	9	TM0515
67	16	TM0523	69	10	TM0517	71	4	TM0522	73	10	TM0515
67	17	TM0523	69	11	TM0517	71	5	TM0522	73	11	TM0515
67	18	TM0523	69	12	TM0517	71	6	TM0522	73	12	TM0515
67	19	TM0523	69	13	TM0517	71	7	TM0515	73	13	TM0522
67	20	TM0517	69	14	TM0523	71	8	TM0515	73	20	TM0522
67	21	TM0517	69	15	TM0523	71	9	TM0515	73	21	TM0522
67	22	TM0517	69	16	TM0523	71	10	TM0515	73	22	TM0522
67	23	TM0517	69	17	TM0523	71	11	TM0515	73	23	TM0522
67	24	TM0517	69	18	TM0523	71	12	TM0515	73	24	TM0515
67	25	TM0517	69	19	TM0523	71	13	TM0522	73	25	TM0515
67	26	TM0517	69	20	TM0517	71	20	TM0522	73	26	TM0515
67	27	TM0517	69	21	TM0517	71	21	TM0522	73	27	TM0515
67	28	TM0517	69	22	TM0517	71	22	TM0522	73	28	TM0515
68	1	TM0516	69	23	TM0517	71	23	TM0522	74	1	TM0515
68	2	TM0516	69	24	TM0517	71	24	TM0515	74	2	TM0522

Figure C-3 CAD Gage Data (cont'd)

M60A1E2 TANK S/N 5511(ET#1) HITPRO EVALUATION TEST DATA
MASTER TAPE INDEX

R	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #	RUN	CHANNEL	TAPE #
-	3	TM0522	75	7	TM0515	91	22	TM0524	92	20	TM0521
74	4	TM0522	75	8	TM0515	91	23	TM0524	92	21	TM0521
74	5	TM0522	75	9	TM0515	91	24	TM0524	92	22	TM0521
74	6	TM0522	75	10	TM0515	91	25	TM0524	92	23	TM0521
74	7	TM0515	75	11	TM0515	91	26	TM0524	92	24	TM0521
74	8	TM0515	75	12	TM0515	91	27	TM0524	92	25	TM0521
74	9	TM0515	75	13	TM0522	91	28	TM0524	92	26	TM0521
74	10	TM0515	75	20	TM0522	92	1	TM0516	92	27	TM0521
74	11	TM0515	75	21	TM0522	92	2	TM0516	98	1	TM0524
74	12	TM0515	75	22	TM0522	92	3	TM0516	98	2	TM0524
74	13	TM0522	75	23	TM0522	92	4	TM0516	98	3	TM0524
74	20	TM0522	75	24	TM0515	92	5	TM0516	98	4	TM0524
74	21	TM0522	75	25	TM0515	92	6	TM0516	98	5	TM0524
74	22	TM0522	75	26	TM0515	92	7	TM0521	98	6	TM0524
74	23	TM0522	75	27	TM0515	92	8	TM0521	98	12	TM0521
74	24	TM0515	75	28	TM0515	92	9	TM0521	98	14	TM0516
74	25	TM0515	91	12	TM0524	92	10	TM0521	98	15	TM0516
74	26	TM0515	91	13	TM0524	92	11	TM0521	98	16	TM0516
74	27	TM0515	91	14	TM0524	92	12	TM0521	98	17	TM0516
74	28	TM0515	91	15	TM0524	92	13	TM0521	98	18	TM0516
75	1	TM0515	91	16	TM0524	92	14	TM0521	98	19	TM0516
75	2	TM0522	91	17	TM0524	92	15	TM0[illegible]1	98	24	TM0521
75	3	TM0522	91	18	TM0524	92	16	TM0521	98	25	TM0521
75	4	TM0522	91	19	TM0524	92	17	TM0521	98	26	TM0521
75	5	TM0522	91	20	TM0524	92	18	TM0521	98	27	TM0521
75	6	TM0522	91	21	TM0524	92	19	TM0521	98	28	TM0521

Figure C-3 CAD Gage Data (cont'd)

There should be 6048 data points for each set of data. The scaling information (RL, RH, TL, TH) are part of the identification record. Note that RL (real low) corresponds to TL (tape low), and RH (real high) corresponds to TH (tape high). CF is conversion factor which may be used to convert the data to different units if necessary. Otherwise, CF must equal 1.0.

The following table list the physical description of each channel:

TABLE C-1 CHANNEL DESCRIPTION

DESCRIPTION	CAD GAGE DATA CHANNEL	GE DATA CHANNEL
Hull yaw rate	1	-
Turret pitch rate	2	-
Turret roll rate	3	1
Azimuth gun rate	4	3
Elevation gun rate	5	2
Azimuth rate command	6	-
Elevation rate command	7	-
Turret/Hull angle	8	-
Gun/Turret angle	9	-
Azimuth position error	10	-
Elevation position error	11	-
Azimuth reticle position	12	7,8
Elevation reticle position	13	6
Turret vertical acceleration	14	9
Turret fore-aft acceleration	15	10
Turret side-side acceleration	16	11
Left front road wheel twist	17	-
Right front road wheel twist	18	-
Track speed (drive sprocket pulse)	19	12
Azimuth motor pressure	20	-
Elevation control pressure	21	-
Supply pressure	22	-
Azimuth servo valve position	23	-
Elevation servo valve position	24	-
Azimuth handle deflection	25	-
Elevation handle deflection	26	-
Elevation tachometer	-	4
Traverse tachometer	-	5

TABLE C-2

SCHEDULE OF RUNS

M60A1E2 TANK S/N 5511 (ET #1) HITPRO EVALUATION TEST

Run No.	Run Type	Course Type	Starting Range	Tank Speed	Target Speed	Gunner	Stab. System	Target Direction	Film Data
1	NF	S	1500	0	15	Y	Y	L-R	N
2	NF	S	1500	0	15	Y	Y	R-L	Y
3	NF	S	1500	0	15	Y	N	R-L	N
4	NF	S	1500	0	15	Y	N	R-L	Y
5	NF	S	1500	0	2	Y	Y	L-R	N
6	NF	S	1500	0	2	Y	N	R-L	Y
7	NF	S	750	0	15	Y	Y	L-R	N
8	NF	S	750	0	15	Y	Y	R-L	Y
9	NF	S	750	0	15	Y	N	L-R	N
10	NF	S	750	0	15	Y	N	R-L	Y
11	NF	Z	-	6	0	Y	Y	-	N
12	NF	Z	-	6	0	Y	Y	-	Y
13	NF	G	-	5	0	N	Y	-	N
14	NF	G	-	5	0	N	Y	-	Y
15	NF	G	-	8	0	N	Y	-	N
16	NF	G	-	8	0	N	Y	-	Y
17	NF	G	-	12	0	N	Y	-	N
18	NF	G	-	12	0	N	Y	-	Y
19	NF	G	-	5	15	Y	Y	L-R	Y
20	NF	G	-	12	15	Y	Y	R-L	Y

*N - no
*Y - yes
*S - stationary
*G - gravel

*B - bump
*Z - zig-zag
*L-R - left-to-right
*R-L - right-to-left

STF - stop-to-fire
F - firing
NF - non-firing

TABLE C-2 (cont'd)

SCHEDULE OF RUNS

M60A1E2 TANK S/N 5511 (ET #1) HITPRO EVALUATION TEST

(Continued)

Run No.	Run Type	Course Type	Starting Range	Tank Speed	Target Speed	Gunner	Stab. System	Target Direction	Film Data
21	NF	G-STF	-	5	15	Y	Y	R-L	Y
91	NF	G-STF	-	5	15	Y	Y	L-R	N
22	NF	G-STF	-	12	15	Y	Y	R-L	N
92	NF	G-STF	-	12	15	Y	Y	L-R	Y
22 prime	NF	G-STF	-	12	15	Y	Y	R-L	N
23	NF	B	-	5	0	N	Y	-	N
24	NF	B	-	5	0	N	Y	-	Y
25	NF	B	-	5	0	Y	Y	-	N
26	NF	B	-	5	0	Y	Y	-	Y
27	NF	B	-	8	0	N	Y	-	N
28	NF	B	-	8	0	N	Y	-	Y
29	NF	B	-	8	0	Y	Y	-	N
30	NF	B	-	8	0	Y	Y	-	Y
31	NF	B	-	5	15	Y	Y	L-R	Y
32	NF	B	-	5	15	Y	Y	R-L	Y
33	NF	B	-	5	15	Y	Y	L-R	Y
34	NF	B	-	5	15	Y	Y	R-L	Y
35	NF	B	-	8	15	Y	Y	L-R	Y
36	NF	B	-	8	15	Y	Y	R-L	Y
37	NF	B	-	8	15	Y	Y	L-R	Y
38	NF	B	-	8	15	Y	Y	R-L	Y

TABLE C-2 (cont'd)

SCHEDULE OF RUNS
M60A1E2 TANK S/N 5511 (ET #1) HITPRO EVALUATION TEST
(Continued)

Run No.	Run Type	Course Type	Starting Range	Tank Speed	Target Speed	Gunner	Stab. System	Target Direction	Film Data
39	F	B	-	8	15	Y	Y	L-R	Y
40	F	B	-	8	15	Y	Y	R-L	Y
41	F	B	-	8	15	Y	Y	L-R	N
42	F	B	-	8	15	Y	Y	R-L	N
43	F	B	-	8	15	Y	Y	L-R	N
44	F	B	-	8	15	Y	Y	R-L	N
45	F	B	-	8	15	Y	Y	L-R	N
46	F	B	-	8	15	Y	Y	R-L	Y
47	F	B	-	8	15	Y	Y	L-R	N
48	F	B	-	8	15	Y	Y	R-L	Y
49	F	B	-	8	15	Y	Y	L-R	Y
50	F	B	-	8	15	Y	Y	R-L	Y
51	F	B	-	8	15	Y	Y	L-R	Y
52	F	B	-	8	15	Y	Y	R-L	Y
53	F	B	-	8	15	Y	Y	L-R	Y
54	F	B	-	8	15	Y	Y	R-L	Y
55	F	B	-	8	15	Y	Y	L-R	Y
56	F	B	-	8	15	Y	Y	R-L	Y
57	F	B	-	8	15	Y	Y	L-R	Y
58	F	B	-	8	15	Y	Y	R-L	Y
98	F	B	-	8	15	Y	Y	R-L	Y

TABLE C-2 (cont'd)

SCHEDULE OF RUNS

M60A1E2 TANK S/N 5511 (ET #1) HITPRO EVALUATION TEST

(Continued)

Run No.	Run Type	Course Type	Starting Range	Tank Speed	Target Speed	Gunner	Stab. System	Target Direction	Film Data
59	F	B	-	8	15	Y	Y	L-R	Y
60	F	B	-	8	15	Y	Y	R-L	Y
61	F	B	-	8	15	Y	Y	L-R	Y
62	F	B	-	8	15	Y	Y	R-L	Y
63	F	B	-	8	15	Y	Y	L-R	Y
64	F	B	-	8	15	Y	Y	R-L	Y
65	F	B	-	8	15	Y	Y	L-R	Y
66	F	B	-	8	15	Y	Y	R-L	Y
67	NF	B	-	12	15	Y	Y	L-R	Y
68	NF	B	-	12	15	Y	Y	R-L	Y
69	NF	B	-	12	15	Y	Y	L-R	Y
70	NF	B	-	12	15	Y	Y	R-L	Y
71	F	S	1500	0	15	Y	Y	L-R	Y
72	F	S	1500	0	15	Y	Y	R-L	Y
73	F	S	1500	0	15	Y	Y	L-R	Y
74	F	S	1500	0	15	Y	Y	R-L	Y
75	NF	Z	-	6	0	Y	Y	-	Y
95	F	B	-	8	15	Y	Y	L-R	Y
76	NF	Z	-	6	0	Y	Y	-	Y
96	F	B	-	8	15	Y	Y	R-L	Y
77	F	B	-	8	15	Y	Y	L-R	Y

TABLE C-2 (cont'd)

SCHEDULE OF RUNS
M60A1E2 TANK S/N 5511 (ET #1) HITPRO EVALUATION TEST
(Continued)

Run No.	Run Type	Course Type	Starting Range	Tank Speed	Target Speed	Gunner	Stab. System	Target Direction	Film Data
78	F	B	-	8	15	Y	Y	R-L	Y
79	F	B	-	8	15	Y	Y	L-R	Y
80	F	S	1500	0	15	Y	Y	R-L	Y
81	F	S	1500	0	15	Y	Y	L-R	Y
82	F	S	1500	0	15	Y	Y	R-L	Y
83	F	S	1500	0	15	Y	Y	L-R	Y
84	F	S	1500	0	15	Y	Y	R-L	Y
85	F	B	-	8	15	Y	Y	R-L	Y
86	F	B	-	8	15	Y	Y	L-R	Y
87	NF	G	-	5	15	Y	Y	L-R	Y
88	NF	G	-	5	15	Y	Y	R-L	Y
89	NF	G	-	8	15	Y	Y	L-R	Y
90	NF	G	-	8	15	Y	Y	R-L	Y

In this program, Channel 9 from Run No. 15 is being copied from tape No. TM0181 to Tape No. TM0090. The first record in each set of data is an identification record similar to the header of a standard label tape. The first 13 characters are used to locate the data. The format of the first 13 characters is as follows:

RUNbbXXbCHbYY

where

b = BLANK

XX = RUN No.

and YY = Channel No.

The following subroutine was written to read the data from the 9-track tape and convert to the proper engineering units:

```
      SUBROUTINE READ90(X,Y,NPTS)
      DIMENSION X(NPTS),Y(NPTS),A1(32)
      READ 1,RL,RH,TL,TH,CF
    1 FORMAT(5F10.0)
      SCALE=(RH-RL)/(TH-TL)
      READ(1,2) A1
    2 FORMAT(32A4)
      PRINT 3,RL,RH,TL,TH,CF
    3 FORMAT(5F12.5)
      PRINT 4,A1
    4 FORMAT(' ',32A4)
      READ(1,5,END=6)(Y(I),I=1,NPTS)
    5 FORMAT(32F4.0)
      GO TO 8
    6 PRINT 7,I
    7 FORMAT(' END OF FILE ON UNIT 1 * * * I=',I5)
      NPTS=I-1
    8 DO 9 I=1,NPTS
      X(I)=FLOAT(I-1)*0.01
    9 Y(I)=((Y(I)-TL)*SCALE+RL)*CF
      RETURN
      END
```

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HITPRO Tests and Analyses
Final Report

Principal Investigator and Compiler: Stanley M. Birley
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247 Pages, Incl Figures

HITPRO is an engineering model that digitally simulates the interactions of the major subsystems of direct fire surface mobile weapons in order to determine overall system accuracy. This report documents the technique used to validate the model with live firing tests.

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HITPRO is an engineering model that digitally simulates the interactions of the major subsystems of direct fire surface mobile weapons in order to determine overall system accuracy. This report documents the technique used to validate the model with live firing tests.

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1. Digital 2. Tests
3. Simulation 4. Data
5. Vehicle 6. Validation
7. Weapons 8. Accuracy

I. Stanley M. Birley
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III. Research Directorate
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Rock Island Arsenal

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HITPRO Tests and Analyses
Final Report

Principal Investigator and Compiler: Stanley M. Birley
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